Design and Fabrication of an Instrument to Test the Mechanical Behavior of Aluminum Alloy Sheets During High-Temperature Gas-Pressure Blow-Forming

by

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Design and Fabrication of an Instrument to Test the Mechanical Behavior of Aluminum Alloy Sheets During High-Temperature Gas-Pressure Blow-Forming

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Dedication

To

my dear aunt,

Martha V. Barrand,

who made all of this possible,

for her endless encouragement and patience.

Acknowledgements

First, I would like to thank my advisor Dr. Eric M. Taleff, for all the time and dedication he devoted toward my research project and for sharing his wisdom.

I want to thank my colleagues in the Mechanical Engineering Department for the countless times they provided me the help required to complete this project.

Finally, I want to thank James D. Smitherman Jr. and Walter B. Cunningham IV at the Chemical Engineering Machine Shop. They not only provided me with the tools and equipment needed for the fabrication of the vast majority of the parts of my project, they also taught me the use of specialized equipment. I couldn't have finished this project without their help and support.

2008

Abstract

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Hydraulic bulge forming has been used as a method to determine the properties of sheet metal alloys in biaxial stretching at room temperature. Gas-pressure bulge forming alleviates the issues of using hydraulic fluids when the tests are conducted at high temperatures (above 200°C). Testing a sheet metal alloy by gas-pressure blow-forming (GPBF) under controlled temperature and pressure conditions requires an accurate and reliable mechanism that delivers repeatable results. It was the purpose of this work to design and implement such an instrument. This instrument should deliver real-time data for material displacement during forming, which can then be used to better understand material plastic response and formability. Four different subsystems within this mechanism must interact, but also have enough independence for analysis and for

assembly purposes. The combined sub-systems produced a GPBF apparatus capable of forming a sheet aluminum alloy AA5182 with a thickness of 1.5 mm into a dome with a height nearly equal to its radius under a constant gas pressure as low as 40 psi at 450°C. This GPBF apparatus produced, for the first time, in-situ data for dome peak displacement during gas-pressure bulge forming of AA5182 sheet at 450°C.

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Chapter 1: Introduction

1.1. BACKGROUND

The use of hot-forming processes such as superplastic forming (SPF) and quick plastic forming (QPF) for aluminum alloy sheets has become a common practice in the automotive industry [1]. Each of these processes is controlled by different creep mechanisms, and they differ in the strain rates and temperatures at which each is performed. Nevertheless, neither one of these processes can be efficiently applied in production without understanding forming limits according to the different deformation regimes involved in each process. When a sheet metal blank is stretched beyond its forming limit for a given strain, strain rate, or temperature, fracture will occur. As the blank stretches, it may thin up to a point where localized thinning produces a neck and fracture ultimately occurs [2]. At elevated temperature, cavitation and cavitation-induced fracture may also limit formability [3].

Forming limit diagrams (FLD's) have become a critical component for characterizing the behavior of sheet-metal during hot-forming processes. Traditionally, an FLD indicated the limiting strains that sheet metals can sustain over a range of major-to-minor strain ratios at room temperature for stamped sheet metal [2]. Substantial work has been devoted to use FLD's as a source for determining the forming limits of aluminum alloy AA5182 during hot forming. FLD's can be constructed by using the strain ratios obtained from hot-forming of tensile tests and gas-pressure bulging experiments [3]. When put together, the failure mechanisms related to each hot-forming process and the FLD's related to each mechanism provide a means to construct and predict the forming limits of aluminum alloys at elevated temperatures.

At room temperature, the hydraulic bulge test is one of the predominant tests used to determine the limiting strains that a sheet metal can sustain over a range of major-to-minor strain ratios [2]. At higher temperatures, forming pressures are significantly reduced, while the availability of hydraulic fluids that can withstand the temperatures is reduced considerably. Gas-pressure bulge tests become a more suitable solution at high temperature. Gas-pressured bulge testing is not a good fit for low-temperature testing, due to the high pressures required for forming at low temperatures. Compressibility issues with the gas used also become difficult to solve.

The development of testing mechanisms to achieve a reliable and repeatable test will provide valuable insight to the future of sheet metal forming by gas-pressure. Introducing the concept of capturing dome-height as a function of time further increases the available data to build the constitutive relationships required to characterize and predict aluminum behavior when hot forming complicated shapes, such as the ones required by the automotive industry in the manufacturing of auto body panels.

1.2. MOTIVATION

Generating the constitutive parameters to accurately model the process of gas-pressure blow-forming requires data from tensile testing and gas-pressure bulge testing. Previously, acquiring data from gas-pressure bulge forming experiments required multiple specimens, each of which was tested to some set dome height prior to failure, and the dome height could only be measured after completion of each test. An instrument that captures the displacement, normal to the surface, of a dome formed on a metal sheet during biaxial bulge forming can further improve simulated models. Having a direct method of measuring the dome displacement in a continuous matter as opposed to calculated from parameters, such as circle grid analysis [2], or intermittent measurements can significantly improve test results. Furthermore, the ability to easily implement new experiments in an instrument that allows the modification of critical specimen geometries, or other test parameters, is very valuable.

1.3. LITERATURE REVIEW

Superplastic forming (SPF) and quick plastic forming (QPF) are both hot blow-forming processes used in the industry to generate automotive body panels [1]. SPF and QPF occur at different temperatures and different strain rates, and both have similar but different deformation mechanisms that govern their behaviors. Forming limit diagrams (FLDs) are being used to determine the limits by which each of these processes can proceed before part failure occurs.

1.3.1. Superplastic Forming (SPF)

SPF is a metal forming process that benefits from the phenomenon of superplasticity to form sheet metal parts of high complexity. Superplasticity is the capability of certain polycrystalline materials to undergo very large plastic strains without necking [4]. Superplasticity requires elevated temperatures and a slow strain rate.

Properties of metals at low-temperatures are not usually strain-rate sensitive. At elevated temperatures (>$0.4T_m$), materials exhibit an increased flow stress with increasing strain rate, i.e. a positive strain-rate sensitivity. True flow stress follows the empirical relationship [6]:

$$\sigma = K \cdot (\dot{\varepsilon})^m , \tag{1.1}$$

Where: σ=true flow stress; $\dot{\varepsilon}$ = true strain rate; m=strain rate sensitivity; and K=a material constant. Superplastic materials, at these elevated temperatures and slow strain rates, exhibit high values of m. While for most metals and alloys, m<0.2, superplastic alloys have values of m>0.4 [4].

Two types of superplastic behavior are well defined according to the literature: Fine-structure superplasticity (FSS), and internal stress superplasticity (ISS). FSS is usually found in materials with a strain-rate sensitivity exponent m=0.5. These materials deform primarily by the grain boundary sliding (GBS) mechanism. ISS materials, on the other hand, typically have an m value of 1, exhibiting Newtonian-viscous flow. ISS materials do not have the fine-grained requirement but only exhibit superplasticity under thermal cycling. These materials deform primarily by slip a deformation mechanism [4]. Our biggest interest is in materials that present the FSS behavior.

Among the most important pre-requisites for developing FSS materials are the fine grain size, the presence of a second phase, the relatively similar strength between phases, and the nature of the grain boundary structure. GBS requires grain boundaries between adjacent matrix grains to be high-angle. Equiaxed grains allow GBS to occur by better allowing grain rotations. Last, the mobility of the grain boundaries provides a reduction of stress concentrations, maintaining GBS as the deformation mechanism [4].

For aluminum alloy AA5083, SPF is conducted at 500°C and strain rates on the order of 10^{-3} to 10^{-4} s^{-1} [1].

1.3.2. Quick Plastic Forming (QPF)

QPF, a proprietary version of hot blow-forming used by General Motors Corp., is a mass-production process used to generate automotive body panels. Different from SPF, QPF operates at lower temperatures and higher strain rates. QPF is also governed by different deformation mechanisms. QPF is governed by two deformation mechanisms: GBS, and solute-drag (SD) creep [3].

QPF of aluminum alloy AA5083 is conducted at 450°C and strain rates on the order of 10^{-2} to 10^{-3} s^{-1} [1].

1.3.3. Forming Limit Diagrams

Forming limit diagrams, as its name implies, have been traditionally used to determine the major and minor strains that sheet metal can sustain during forming [2]. Major and minor strains are referred to the strains that the sheet metal sees in the two axes contained in the sheet metal plane. The third axis, normal to the plane (sheet thickness) is not plotted in the FLD.

According to literature, it is customary to graphically represent the strain state of a deformed sheet by plotting the major strain, e_1, on the vertical axis, and the minor strain, e_2, on the horizontal axis. If one is to print or etch an array of small diameter, evenly spaced circles on the critical strain regions of the sheet to be deformed (referred to in the literature as circle grid analysis), it is possible to determine the strain state at a particular region on a blank [2].

The shape and direction of the deformed circles determine the mode of stretching of the sheet, as shown in Figure 1.1. The strain path immediately to the left of the major strain axis, e_1, corresponds to the strain ratio developed in the uniaxial tension test. The region in the center, where the minor strain e_2 =0, corresponds to the strain developed in a plane strain bulge test. The region to the right of the major strain axis corresponds to the strain ratio developed in biaxial bulge testing. Finally, the diagonal of this region, where e_1=e_2 corresponds to the balanced biaxial stretching [2]. Figure 1.2 shows the mechanical tests performed to achieve the different strain states required to generate the forming limit diagram: (a) uniaxial tensile test, (b) plane strain bulge test, (c) balanced biaxial bulge test [1].

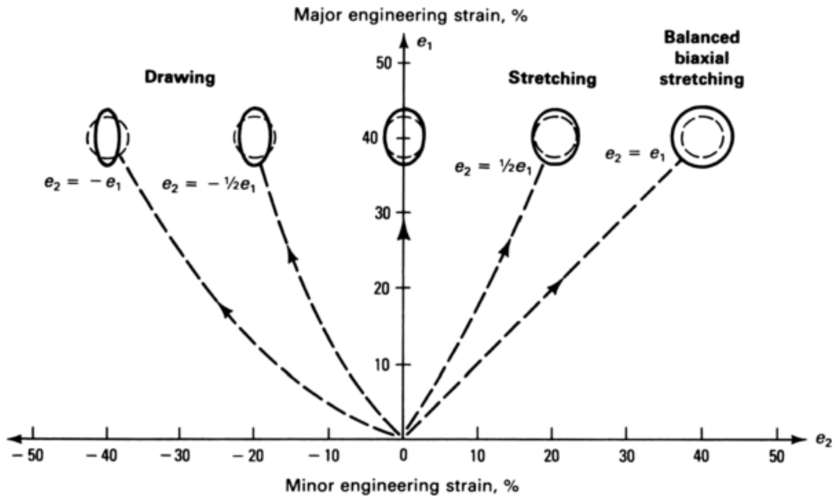


Figure 1.1: Schematic of several major-to-minor strain combinations, from [2].

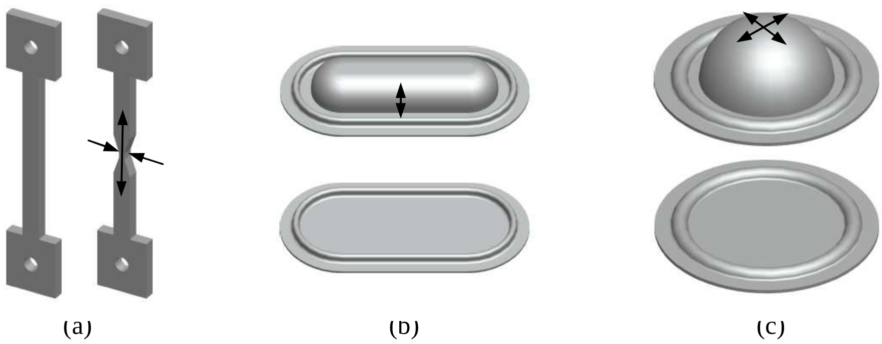


Figure 1.2: Mechanical tests performed to achieve the different strain states to generate the forming limit diagram: (a) uniaxial tensile test, (b) plane strain bulge test, (c) balanced biaxial bulge test, from [1].

Following the traditional method of calculating FLD's for stamped metal at room temperature conditions, the lowest major strain is obtained when the minor strain, $e_2 = 0$ (Figure 1.3). This is the case of plane strain [2].

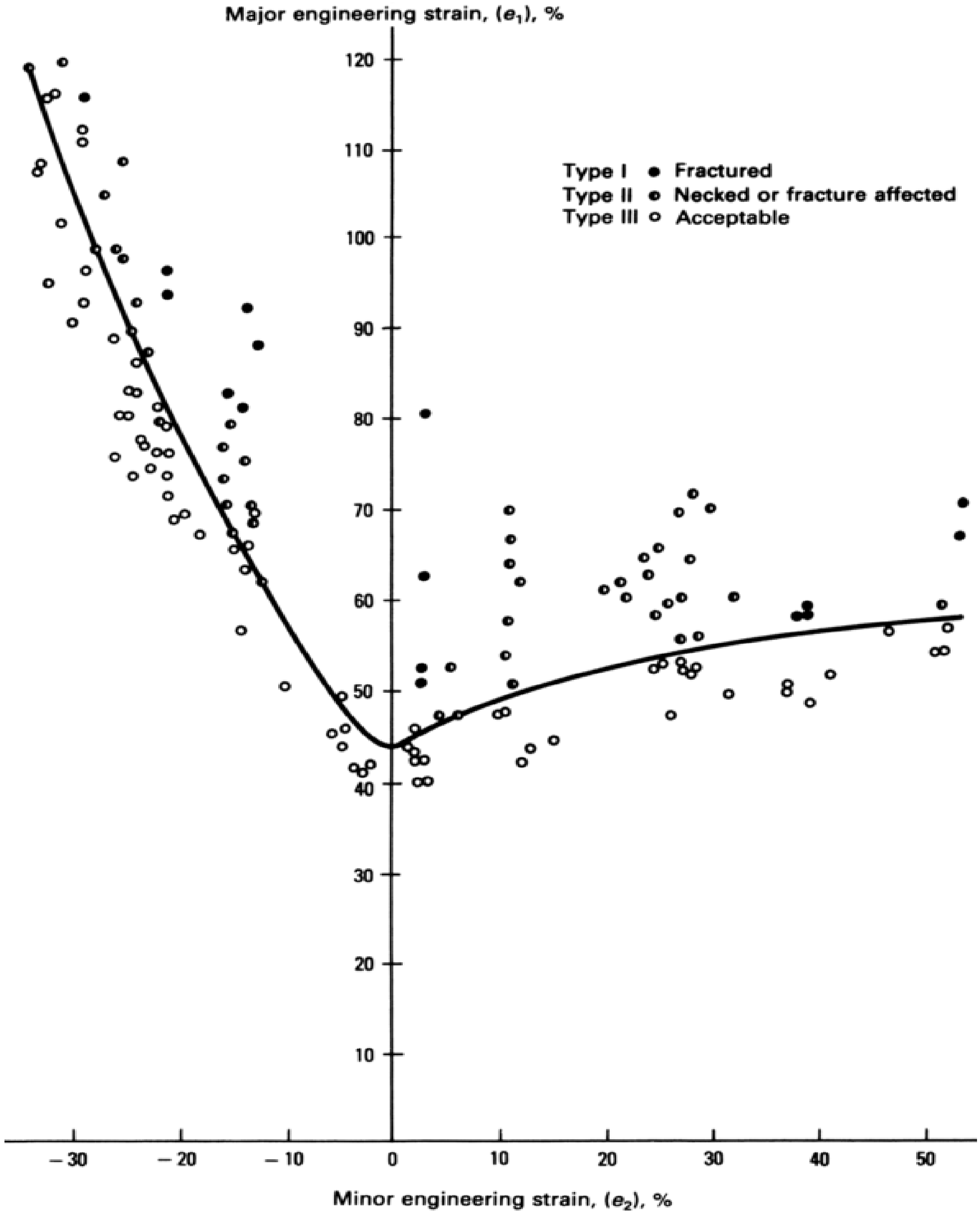


Figure 1.3: Strain measurements and forming limit diagram for aluminum-killed steel, from [7].

According to the work of Kulas et al. [1] in their publication of "Forming Limit Diagrams for AA5083 under SPF and QPF Conditions", it is seen that the FLD curve for aluminum alloy AA5083 under QPF conditions (strain rate = $10^{-2}s^{-1}$ and T=450°C) shows that the lowest major strain corresponds to the case of balanced biaxial conditions (Figure 1.4). Moreover, the FLD curve for SPF conditions (strain rate = $10^{-3}s^{-1}$ and T=500°C) shows a similar shape, with the lowest major strain also corresponding to the case of balanced biaxial conditions (Figure 1.5).

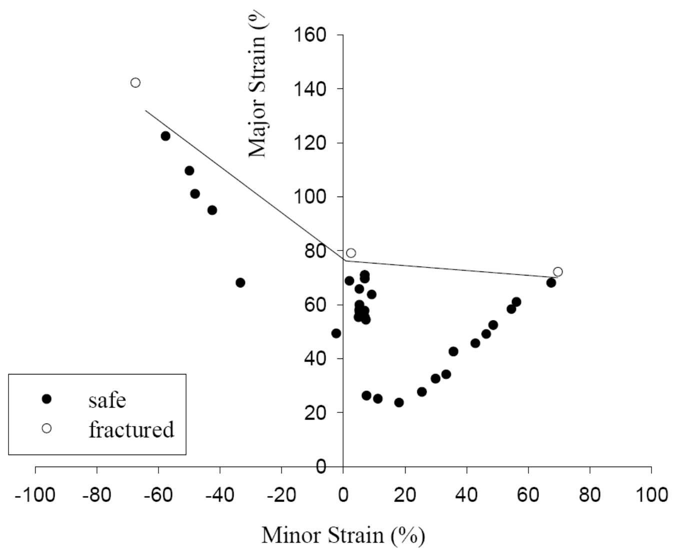


Figure 1.4: Forming limit diagram for AA5083 for QPF conditions of 450°C and $10^{-2}s^{-1}$ based on fracture criteria, from [1].

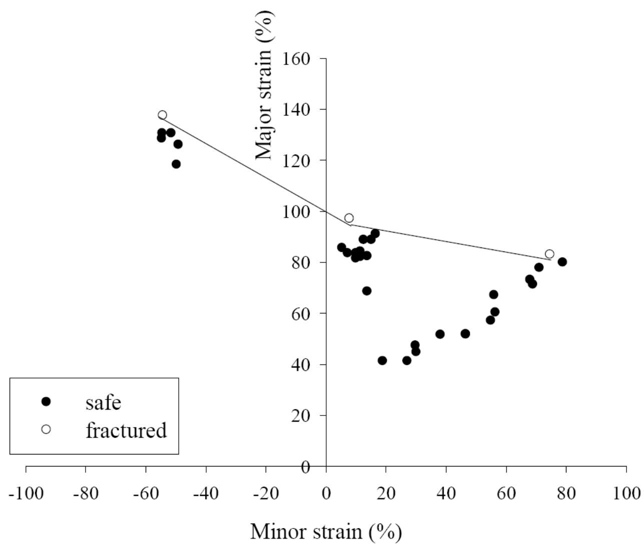


Figure 1.5: Forming limit diagram for AA5083 for SPF conditions of 500°C and $10^{-3}s^{-1}$ based on fracture criteria, from [1].

These results play an important roll in determining the most critical strain ratio during bulge forming. Balanced biaxial bulge forming has the lowest major strain value for failure during QPF and SPF operations. For this reason, the balanced-biaxial bulge test is the most important mean of evaluating material formability for SPF or QPF conditions. This is the experiment addressed by the instrument produced in this study.

Chapter 2: Design Process

2.1. Problem Statement

The objective of this project was to design and fabricate an instrument to test the mechanical behavior of aluminum alloy sheets during high-temperature gas-pressure blow-forming (GPBF). Once completed, this instrument will evaluate the flow properties and the failure mechanisms of aluminum alloy sheets under balanced biaxial tension.

From direct results of these tests, the following two parameters will be observed and described in detail:

a. The flow properties of the aluminum alloy sheet while under the conditions of balanced biaxial stress;

b. The failure mechanism(s) seen at the fracture-point of the specimen during bulge testing. This fracture point should be located within the region of balanced biaxial stress.

2.2. Design Requirements

All mechanical components of the instrument must meet the minimum criteria of the physical dimensions of provided components, like the furnace and the servo-hydraulic system for tension-compression testing. Certain components of this instrument also must sustain the temperature requirements at which tests are expected to be performed.

Figures 2.1 and 2.2 show the overall dimensions and specifications for the furnace and the servo-hydraulic unit used in conjunction with the instrument produced in this study.

ATS Furnace Specifications

Model	ATS-3210
Watts	2640
Amps/Zone	6.5
Connection	2-1500-1
Max. Temp.	1200°C

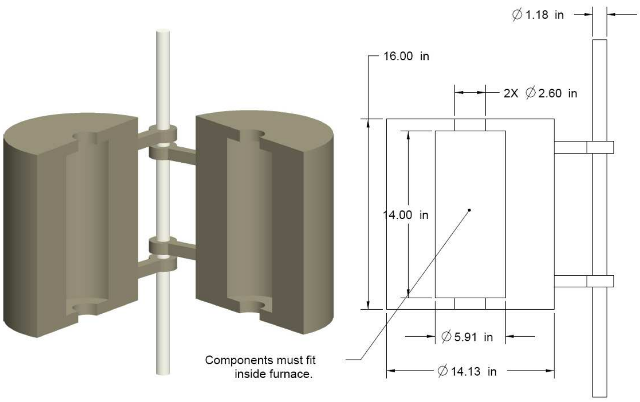


Figure 2.1: Overall dimensions and specifications of furnace unit.

MTS Servo Hydraulic Unit Specifications

Model	MTS 318.25
Force Capacity (maximum)	250 kN (55 kip)
Vertical test space, (A)	1625 mm (64 in)
Working height (B)	889 mm (35 in)
Column spacing (C)	635 mm (25 in)
Column diameter (D)	76 mm (3 in)
Base width (E)	1003 mm (39.5 in)
Base depth (F)	762 mm
Diagonal clearance (G)	3251mm (128 in)
Overall height (H)	3023 mm (119 in)
Stiffness	4.3×10^{8} N/m (2.4×10^{6} lb/in)
Weight	910 kg (2000lb)
Load cell rating (max)	100 kN (22kip)

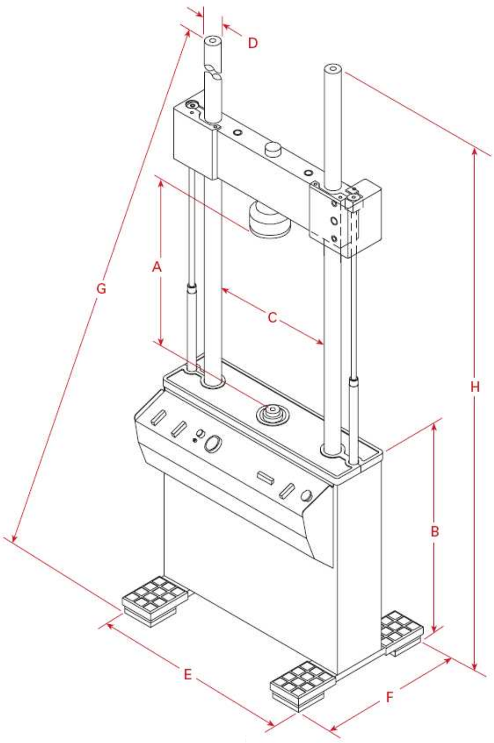


Figure 2.2: Overall dimensions and specifications of servo-hydraulic unit.

Mechanical components within the furnace must:

- Reside inside the physical dimensions of furnace, and
- Maintain the minimal mechanical properties such as yield strength and modulus of elasticity at the temperatures required to achieve gas-pressure blow-forming (GPBF).

The following are the minimum design requirements expected of the GPBF apparatus once completed and operational:

- Capable to sustain the testing of specimens at temperatures ranging 400°C (752°F) up to 600°C (1112°F);
- Capable of testing specimens of sheet thickness up to 1.53 mm (0.060 in);
- Capable of forming over a sheet area at least 11 cm^2 (1.70 in^2);
- Capable of sustaining forming pressures up to 1400 kPa (203 psi);
- Gas-pressure fittings and pipelines must be rated to at least twice the minimum forming pressure requirements;
- Within the hot zone, at least one layer of protection must be placed between the gas pressure lines and the user. Rupture of the end of the gas-pressure line within the hot zone must be contained by the structure.

2.3. DELIVERABLES

Completion of this work will be finalized with an instrument capable of reproducing the conditions required for SPF and QPF in a balanced biaxial bulge test. This instrument will be composed of four subsystems. These subsystems are: (a) the loading columns, (b) the clamping mechanism, (c) the system to capture dome-peak displacement, and (d) the gas-pressure lines for gas-pressure forming. Although all four subsystems directly interact, maintaining some independence between their designs elements makes maintenance and redesign easier.

Proper usage of the complete instrument within the recommendations of chapters 3 and 4 should allow the user to obtain repeatable results when using the same settings. These results should also be within the lowest margin of error of the instrumentation and within the statistical mean of the mechanical failure modes presented during the conditions of balanced biaxial bulge forming.

2.4. DESIGN VARIANTS

A common standard method to test the properties of sheet metal in biaxial stretching without involving surface friction is the hydraulic bulge test [2]. A round sheet-metal blank is clamped between circular or elliptical die-rings. A lock-bead along the periphery of the die-rings (Figure 2.3), forms a draw-bead in the specimen's periphery as the specimen is clamped between the dies. The lock-bead consists of a ridge of small radius on one ring and a groove of similar but larger size on the other ring [2]. The groove on one of the die-rings must be designed for a range of sheet-metal thicknesses. The formed draw-bead around the periphery of the specimen prevents the specimen from slipping [2]. The final apparatus will form a sheet blank with an outer diameter of 3.55 in. into a cylindrical cavity with a diameter of 2.18 in. and an entry chamfer of 0.030 in.

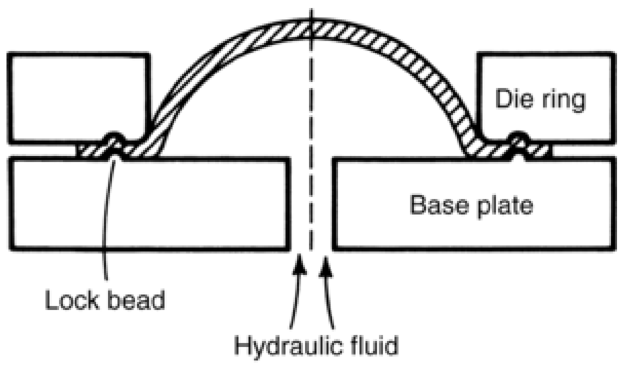


Figure 2.3: Schematic of hydraulic bulge test, from [2].

As mentioned in chapter 1.1, the high-temperature low-pressure requirements make the use of gas as the pressurizing fluid a better fit over a hydraulic fluid.

The first preliminary design had the intention of defining the shape of the die-rings and the draw-bead on the die-rings. Particular attention was given to the interface of the die-rings to the overall assembly. The first priority was to solve the problem of interfacing for the die-rings to the entire structure. The design should allow an easy replacement of the dies without having to remove the entire setup out of the servo-hydraulic unit. The addition of die-holders to the design solved this issue. Die-holders would have a six-bolt pattern to hold the die in place. Bolts in the six-bolt pattern are not expected to see any torsional or compressive loading, making the release and the wear on them of little concern (Figure 2.4).

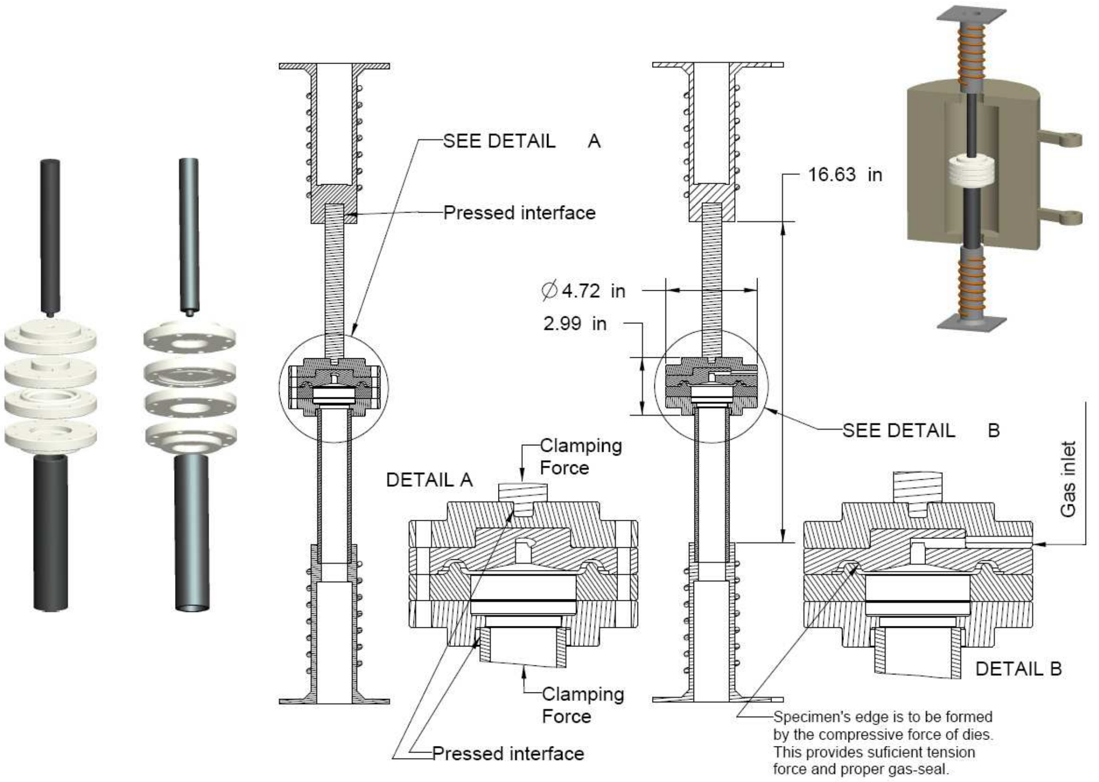


Figure 2.4: Preliminary design of circular die-rings for gas-pressure blow-forming.

2.5. RELEVANT CALCULATIONS

The preliminary concept provided the starring point for the design of the entire mechanism. All other components would be designed around the die-rings concept. Overall, it was necessary to understand which subsystems where exposed to the loading and/or temperatures requirements and how these two combined, affecting the mechanical analysis made for each component. It was important to define the loads and the minimum requirements for these loads to occur safely. The two most critical loads expected to be developed during operation are: the forming of the draw-bead, requiring a compressive load (Figure 2.5(a)); maintaining the dies closed during the bulge-forming, requiring a compressive load (Figure 2.5 (b)).

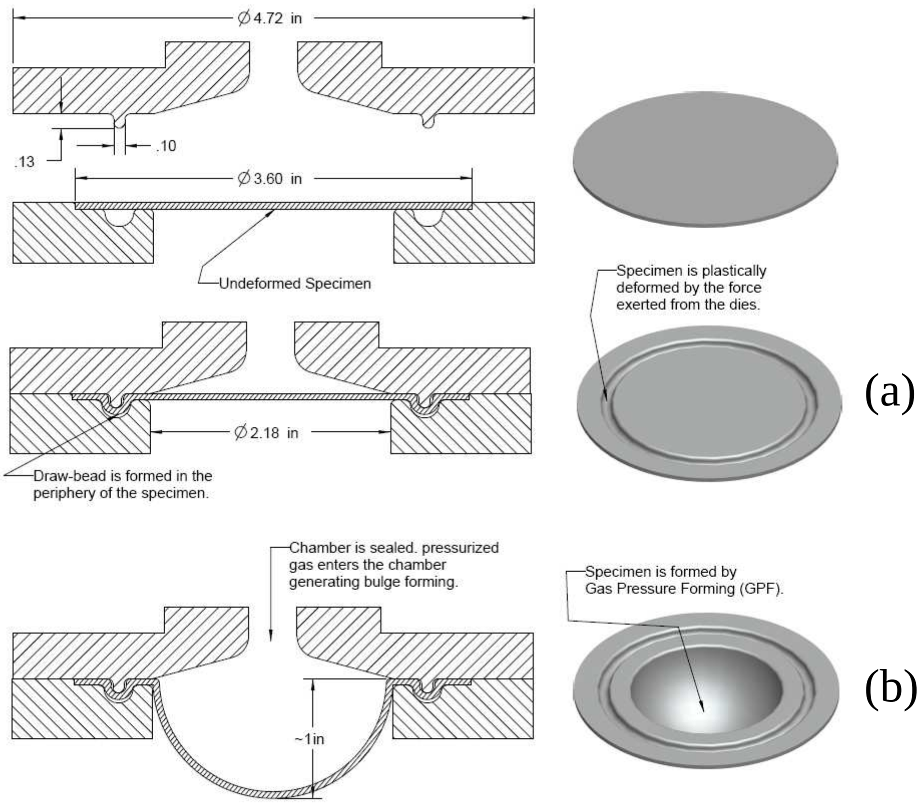


Figure 2.5: Two-step forming of sheet-metal blank: (a) forming of the draw-bead by the clamping of die-rings, (b) forming of the dome by gas-pressure blow-forming.

The approach taken was to calculate the values for the forming of the draw-bead and the clamping of the die-rings during gas-pressured bulge forming. These values would be used as the minimum requirements for the loading column to sustain. These values will also provide the most suitable pipe size and length that could fit mechanical constraints, such as furnace internal dimensions, height of the servo-hydraulic unit, and the minimum requirements from buckling analysis.

The calculations required for the gas-pressure lines were based on the minimum forming pressure requirements at the temperature requirements. Information from the Swagelok® was readily available, shortening the design process. See Appendix A.

Finally, thermal expansion calculations were taken in consideration. To minimize the distortion due to thermal expansion, components within the heating largely affected in length by thermal expansion were made on the same material composition, i.e., Austenitic stainless steel 316.

2.5.1. Forming of the Draw-bead

As the round sheet-metal blank is clamped between circular die-rings, a draw-bead, in the periphery of the blank, is formed (Figure 2.3). To model the forming of the draw-bead, one can use an approximate variation of a well-characterized problem in the literature, deep-drawing or cupping. One requirement for deep drawing is that the edges of the dies (in this case, the edges of the lock-bead, ridges and groove, Figure 2.3) must have well-rounded edges; otherwise the blank might be sheared [8]. The goal of this analysis is to provide a close estimate of the force required to generate the draw-bead; its intention is not to characterize it in detail, but instead to use these results for the design and construction of the loading column.

To calculate the required load to generate the forming of the draw-bead, the system was approximated to the case of deep drawing. The process was broken down into two deep-drawing passes. In the first pass, the sheet-metal blank is drawn downward, generating a cup as shown in Figure 2.6(b); in the second pass, the die-rings make an upward drawing (Figure 2.6(c)). The end result is the draw-bead (Figure 2.6(a)).

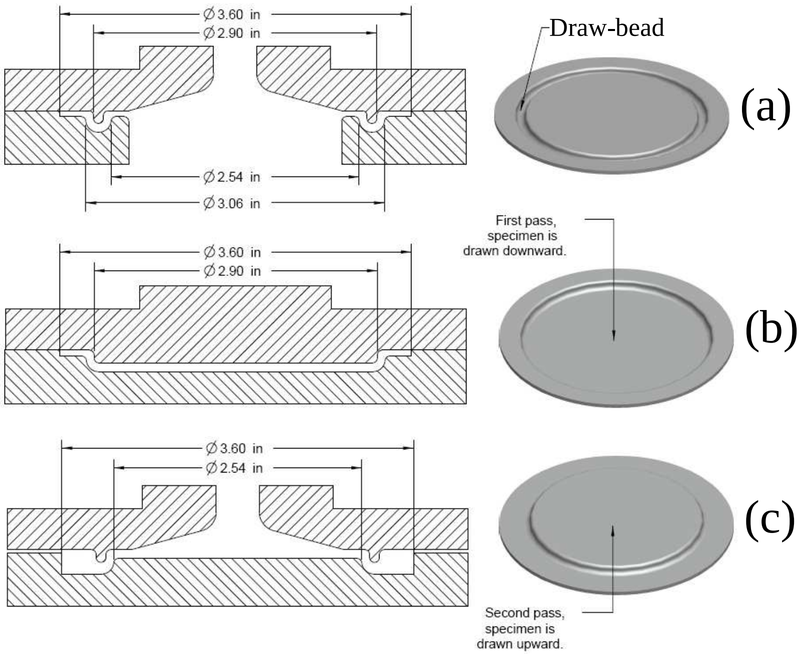


Figure 2.6: Forming of the draw-bead by two deep-drawing passes: (a) sheet metal blank after two-step deep drawing; (b) first pass, blank is drawn downward; (c) second pass, blank is drawn upward.

Using the method provided by Schey [8] to obtain the estimated force for deep-drawing (Figure 2.7):

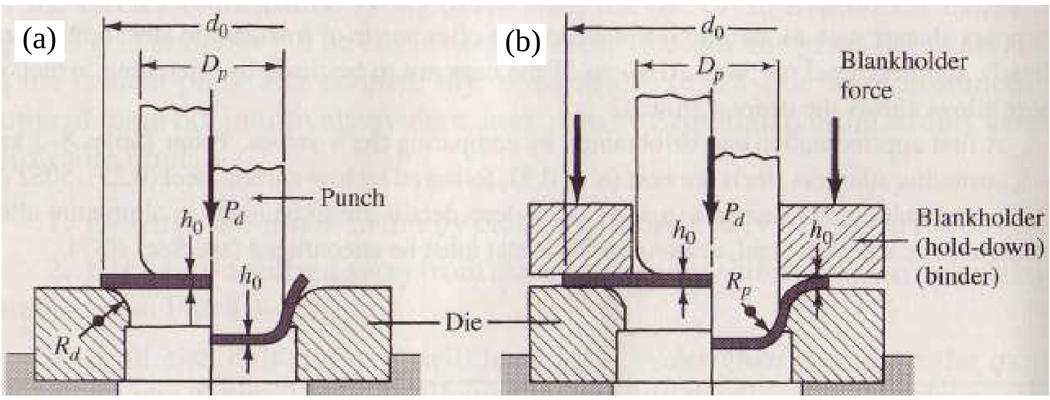


Figure 2.7: Deep-drawing process: (a) no blank-holder; (b) with blank-holder, from [8].

$$P_d = \pi \cdot D_p \cdot h \cdot UTS \cdot \left(\left(\frac{d_o}{D_p} \right) - 0.7 \right) \quad (2.1)$$

Where: P_d=drawing force; UTS=Ultimate Tensile Strength; other dimensions, see Figure 2.7. For the case of forming the draw-bead:

$$P_F = P_{d\text{-first pass}} + P_{d\text{-second pass}} \quad (2.2)$$

Table 2.1 shows the forming force, P_F, required to form the draw-bead as a function of temperature for aluminum alloy AA5182. UTS values for AA5182 at the different temperatures were obtained from the work of Brian Chang, PhD. candidate in Materials Science.

Table 2.1: Forming force, P_F, required to form the draw-bead for aluminum alloy AA5182 as a function of temperature.

				Deep drawing of First Pass			**Deep drawing of Second Pass**			**P_F = $P_{d\text{-f-p}}$ + $P_{d\text{-s-p}}$**
Sheet thickness, in	**Temperature, °C**	UTS, Mpa	UTS, ksi	D_p, in	d_o, in	$P_{d\text{-first pass}}$, lbf	D_p, in	d_o, in	$P_{d\text{-second pass}}$, lbf	**P_F, lbf**
0.04	25	420	60.9	2.9	3.6	12015	2.54	3.6	13944	25959
0.04	300	150	21.75	2.9	3.6	4291	2.54	3.6	4980	9271
0.04	350	100	14.5	2.9	3.6	2861	2.54	3.6	3320	6181
0.04	400	65	9.425	2.9	3.6	1859	2.54	3.6	2158	4017
0.04	**450**	45	6.525	2.9	3.6	1287	2.54	3.6	1494	**2781**

The heavy dependence of temperature makes the forming of the draw-bead most suitable at the temperature requirements for gas-pressure blow-forming.

Table 2.2 shows the forming force, P_F, required to generate the draw-bead as a function of sheet thickness for aluminum alloy AA5182. The temperature value for these calculations was kept constant; the value used is the required temperature to achieve QPF conditions.

Table 2.2: Forming force, P_F, required to form the draw-bead for aluminum alloy AA5182 as a function of sheet-metal thickness for a set temperature value.

				Deep drawing of First Pass			Deep drawing of Second Pass			$P_F = P_{d\text{-}f\text{-}p} + P_{d\text{-}s\text{-}p}$
Sheet thickness, in	**Temperature, °C**	UTS, Mpa	UTS, ksi	D_p, in	d_o, in	$P_{d\text{-first pass}}$, lbf	D_p, in	d_o, in	$P_{d\text{-first pass}}$, lbf	**P_F, lbf**
0.04	450	45	6.525	2.9	3.6	1287	2.54	3.6	1494	2781
0.045	450	45	6.525	2.9	3.6	1448	2.54	3.6	1681	3129
0.05	450	45	6.525	2.9	3.6	1609	2.54	3.6	1867	3477
0.055	450	45	6.525	2.9	3.6	1770	2.54	3.6	2054	3824
0.06	**450**	45	6.525	2.9	3.6	1931	2.54	3.6	2241	**4172**

Thickness of sheet-metal blank also affects the force required to form the draw-bead. However, temperature dependence plays a bigger role over sheet thickness. From this point on in the design, calculations will use the value obtained for the thickest sheet metal blank at the temperature requirements for QPF:

$$P_F = 4200 \text{ lbf} \tag{2.3}$$

2.5.2. Pressure Requirements for Bulge Forming

The next step is to estimate the clamping force. This is the force required to maintain the die-rings pressing the formed draw-bead in the sheet-metal blank against one another to avoid slipping of the sample and to provide seal from gas-leakage. Defining the clamping force as:

$$F_C = \frac{P_S}{A_F} \tag{2.4}$$

Where: F_c= Clamping force; P_S= pressure required to form the sheet-metal blank for QPF and SPF conditions; and A_F= Projected area of the sheet-blank to be formed by gas-pressure blow-forming.

According to the work of Hector et al. [10] in “Material Models for Simulating Elevated-Temperature Pneumatic Bulge Forming of AA5083 Sheet”, pressure requirements to achieve the strain rate conditions for QPF and SPF can be as low as 26 psi or as high as 130 psi [10]. Table 2.3 shows the clamping force required when choosing a projected area for a clearance-hole diameter of 2.5 in.(Figure 2.6).

Table 2.3: Clamping force, F_C, as a function of the pressured required to achieve the strain rate conditions of SPF and/or QPF.

Pressure, psi	Projected area, A_F, in^2	**P_F, lbf**
26	4.91	**128**
130	4.91	**638**
200	4.91	982
250	4.91	1227
300	4.91	1473

Even at pressures higher than the ones required to achieve the strain rate conditions for SPF or QPF, the clamping force is much lower than the force required to form the draw-bead (Eqn. 2.3). Buckling analysis will use the force calculated to form the draw-bead (Eqn. 2.3) since this compressive force (force to form the draw-bead) certainly takes care of the compressive force requirements to maintain the die-rings clamped during the gas-pressure blow-forming.

2.5.3. Buckling Analysis of Columns

Once the estimated loads for the forming of the sheet-metal blank during testing were calculated (forming of the draw-bead and clamping force during bulge-forming), the next step was to design a loading-column that would support the dies in place inside the furnace. As one can see from Figure 2.8, the die-rings and the die-holders will be inside the furnace, while the pipes supporting the die-holders will have one end inside the furnace and the other end in direct contact with the heat exchanger.

It was critical to calculate, based on the overall servo-hydraulic testing machine dimensions (Figure 2.8), the critical pipe size that would sustain the expected loads at the required temperatures, while at the same time fit the furnace's inner dimensions. It was also critical to keep in mind that the temperature at either end of the loading column outside the furnace must be maintained close to room temperature by means of heat-exchangers. One end of the loading column will be in direct contact to a load-cell, while the other end will be in close contact to all the instrumentation for recording dome-height during bulge-forming. Both the load-cell and additional instrumentation must be isolated from the heat of the furnace.

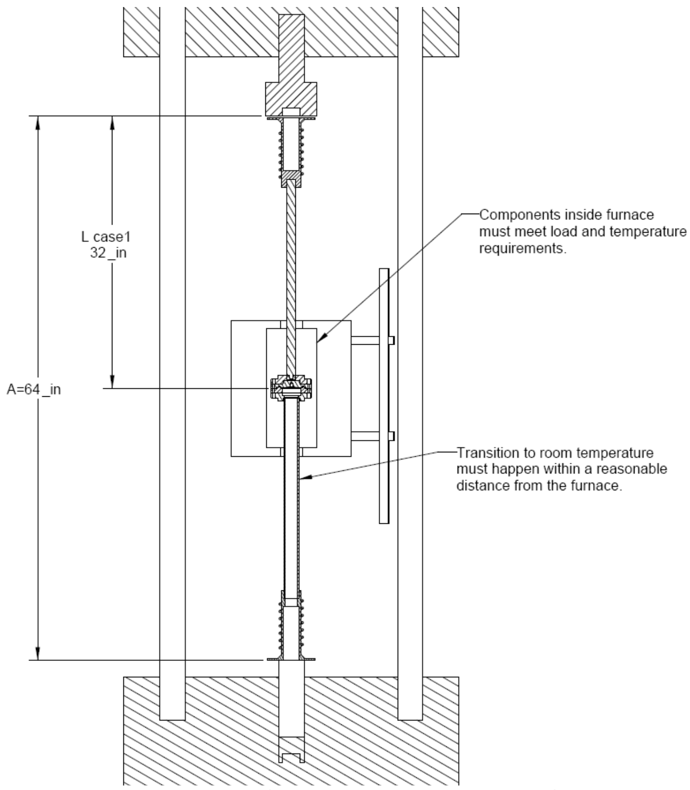


Figure 2.8: Overall dimensions used for buckling analysis of the loading column.

Buckling analysis was needed at the temperatures required to achieve QPF and SPF conditions (450°C (842°F) or 500°C (932°F)). Mechanical properties of two of the most common alloys used in high-temperature applications, austenitic stainless steel 316 and INCONEL® alloy 600, were obtained (Figure 2.9) [11, 12, and 13]. Within the temperature requirements, 0.2% yield strength and modulus of elasticity remained quite high.

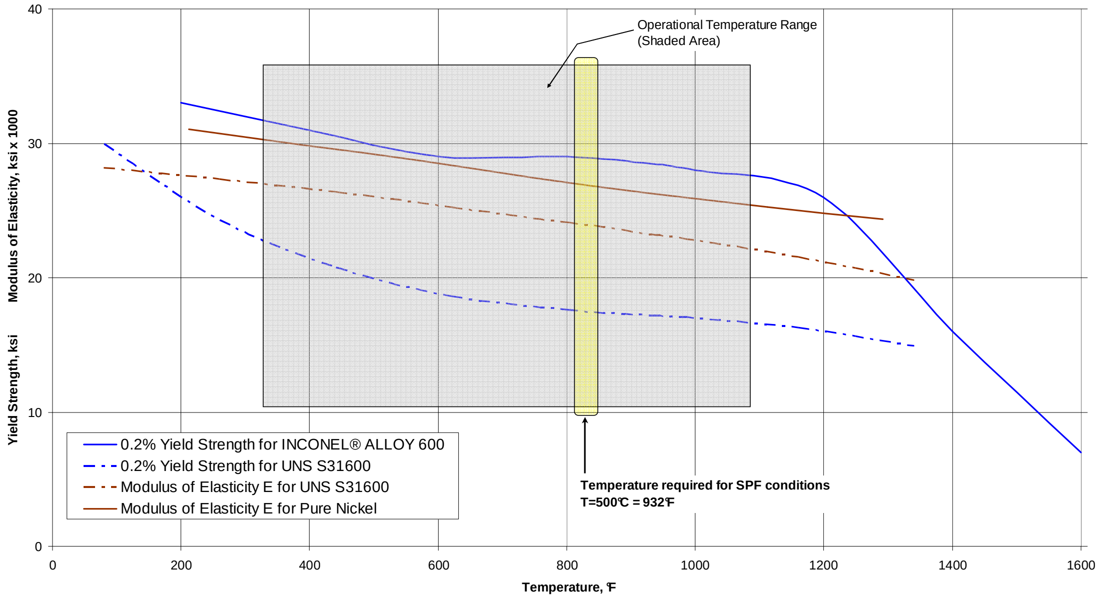


Figure 2.9: 0.2% yield strength and modulus of elasticity for austenitic stainless steel 316 and INCONEL® alloy 600 as a function of temperature, from [11, 12, and 13].

Using the mathematical models from Karditsas et al. [11] for modulus of elasticity and yield strength as a function of temperature for austenitic stainless steel 316 the following values were obtained:

$$E_{SS316@932°F} = 23210 \text{ ksi} \tag{2.6}$$

$$\sigma_{y\ SS316@932°F} = 17.2 \text{ ksi} \tag{2.7}$$

Interpolating data from A-1© Wire Tech, Inc. [12] for yield strength of INCONEL® ALLOY 600 the following value was obtained:

$$\sigma_{y\ INC600@932°F} = 28.5 \text{ ksi} \tag{2.8}$$

Data for the modulus of elasticity of INCONEL® ALLOY 600 as a function of temperature was not available. Data from Koster [13] for pure Nickel was used:

$$E_{Nickel@932°F} = 26245 \text{ ksi} \tag{2.9}$$

The buckling analysis covered all the different pipe schedules that could meet the mechanical constraints of the project. This analysis was intended to select the pipe schedule (schedule refers to diameter and wall thickness according to ASTM standards) that could meet the loading and mechanical constraints. The analysis for imperfect columns that follows the buckling analysis was intended to provide the minimum machining and assembly alignment requirements for the entire assembly. This analysis gives validity to the buckling analysis, since imperfections in the machining and assembly process are unavoidable in manufacturing.

To model the loading column that holds the die-rings in place, the Euler buckling theory for modeling a straight column that is simply supported at one end was used. According to this model, any expected bending is assumed to occur in the same axis of the load, the Z-axis [9]. For the case of one end fixed one end free, the critical buckling load, P_{cr}, is defined as [9]:

$$P_{cr} = \frac{\pi^2 \cdot E \cdot I}{4 \cdot L^2} = \frac{\pi^2 \cdot E \cdot I}{(2 \cdot L)^2} \tag{2.10}$$

Where: E= young's modulus; I= area moment of inertia of column; L= length of column; and L_{eff} = effective length of the column. Replacing Eqn. 2.11 in Eqn. 2.12 [9]:

$$L_{eff} = 2 \cdot L \tag{2.11}$$

$$P_{cr} = \frac{\pi^2 \cdot E \cdot I}{(L_{eff})^2} \tag{2.12}$$

It is important to define the term called effective length of the column (L_{eff}) for the analysis of imperfect column. Defining the compressive axial stress, $\sigma_{cr,}$ just before the column would buckle [9]:

$$\sigma_{cr} = \frac{P_{cr}}{A} \tag{2.13}$$

Where A= cross sectional area of the column. Defining the radius of gyration, *r* [9]:

$$r = \sqrt{\frac{I}{A}} \tag{2.14}$$

And keeping in mind the column is to be loaded within its elastic region only [9]:

$$\sigma_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 \cdot E}{\left(\frac{L_{eff}}{r}\right)^2} \text{ ; as long as } \sigma_{cr} < \sigma_{yield} \text{ .} \tag{2.15}$$

The failure envelope is defined as the point on the plot in Figure 2.10 when the compressive axial stress σ_{cr} reaches the yield stress σ_{yield} [9]:

$$\sigma_{cr} = \sigma_{yield} \text{ , } \frac{\sigma_{cr}}{\sigma_{yield}} = 1 \tag{2.16}$$

According to Vable [9], short column design is based on the yield stress as the failure stress, while long column design is based on critical buckling stress.

The first step in this procedure is to solve Eqns. 2.4, 2.6, 2.7, and 2.8 for the different available pipe schedules that could possibly fit the mechanical constraints of the furnace. Table 2.4 shows the inner diameter, outer diameter and the basic calculations required to solve the required formulas.

Table 2.4: Different pipe sizes for the different schedules for austenitic stainless steel 316 seamless pipe, according to ASTM B-167.

Nominal Size, in.	Schedule	Outside Diameter, in.	Nominal Wall thickness, in.	Inside Diameter, in.	Area Moment of Inertia I, in.^{4}	Cross Sectional Area A,in.^{2}	Radius of Gyration $r=\sqrt{(I/A)}$	Slenderness Ratio (L_{eff}/r) for Case 1: L=32in., L_{eff} =64in.
1	10	1.315	0.109	1.097	0.08	0.41	0.43	149.5
1	40	1.315	0.133	1.049	0.09	0.49	0.42	152.2
1	80	1.315	0.179	0.957	0.11	0.64	0.41	157.4
1.5	10	1.9	0.109	1.682	0.25	0.61	0.63	100.9
1.5	40	1.9	0.145	1.61	0.31	0.80	0.62	102.8
1.5	80	1.9	0.2	1.5	0.39	1.07	0.61	105.8
2	10	2.375	0.109	2.157	0.50	0.78	0.80	79.8
2	40	2.375	0.154	2.067	0.67	1.07	0.79	81.3
2	80	2.375	0.218	1.939	0.87	1.48	0.77	83.5
2.5	10	2.875	0.12	2.635	0.99	1.04	0.97	65.6
2.5	40	2.875	0.203	2.469	1.53	1.70	0.95	67.6
2.5	80	2.875	0.276	2.323	1.92	2.25	0.92	69.3

The vertical test space, defined as variable A from Figure 2.2 is 64 in. according to manufacturer. Taking the worst two scenarios:

-Case 1: Half the longest possible loaded-column =64 in./2 = 32 in.

$$L_{CASE\ 1}=32 \text{ in.} \tag{2.17}$$

-Case 2: Half the height of the furnace plus twice the height of an available heat exchanger =24 in./2 = 12 in.

$$L_{CASE\ 2}=12 \text{ in.} \tag{2.18}$$

Solving Eqn. 2.12, Eqn. 2.13, and comparing σ_{cr} to σ_y as Eqn. 2.16, the results for case 1 (Eqn. 2.17) were obtained (Table 2.5):

Table 2.5: Calculated values for buckling analysis for case 1, L=32 in

Nominal Size, in	Schedule	Critical Buckling Load (P_{cr}) for Case 1: L=32in, L_{eff} =64in, kip	Compressive Axial Stress at Critical Buckling Load (σ_{cr}) for Case 1: L=32in, L_{eff} =64in, ksi	σ_{cr} / σ_y
1	10	4.23	10.25	0.60
1	40	4.88	9.89	0.58
1	80	5.91	9.25	0.54
1.5	10	13.80	22.51	1.31
1.5	40	17.33	21.68	1.26
1.5	80	21.88	20.48	1.19
2	**10**	**27.92**	**35.98**	**2.09**
2	**40**	**37.23**	**34.65**	**2.01**
2	**80**	**48.54**	**32.86**	**1.91**
2.5	10	55.21	53.16	3.09
2.5	40	85.54	50.20	2.92
2.5	80	107.62	47.75	2.78

Plotting the ratio σ_{cr} to σ_y, σ_{cr}/σ_y, as a function of the slenderness ratio, (L_{eff} /r), one can construct the failure envelope for each pipe schedule and determine which pipe schedule is more prone to fail by buckle or by yield (Figure 2.10).

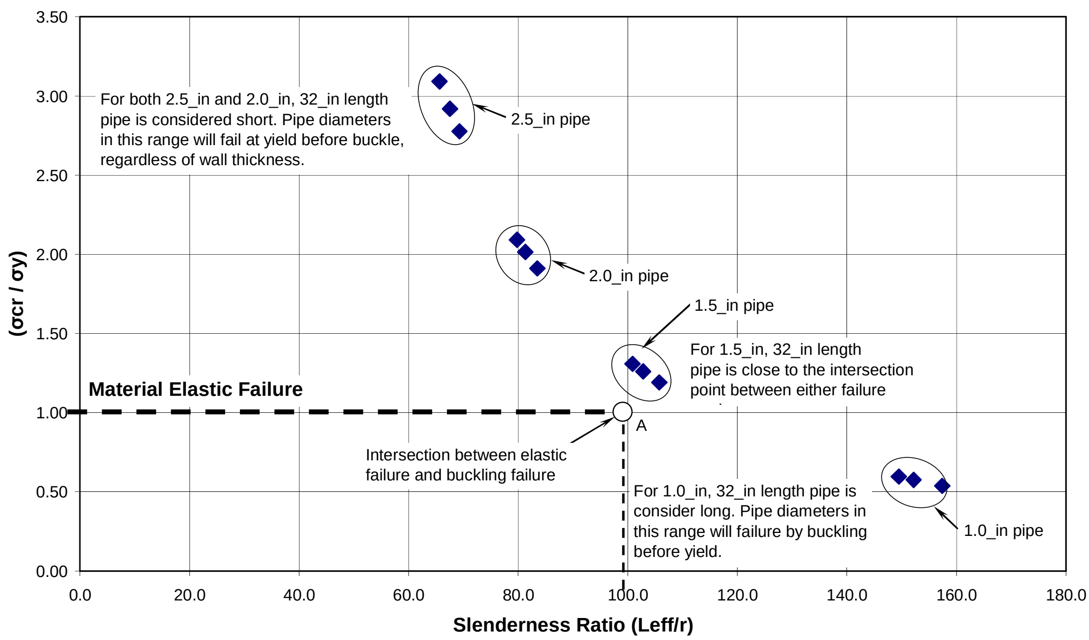


Figure 2.10: Failure envelope for austenitic stainless steel 316 seamless pipe for the different schedules available according to ASTM B-167, for the case 1, L=32 in.

By using 2.0 in. pipe schedule (regardless of the different schedules), the risk of buckling for a pipe length of 32 in. is negligible. A 1.5 in. pipe schedule is not suitable for the pipe length requirement since it is too close to both buckling and yielding failure regimes.

Finally, a factor of safety before yield was obtained for the case load of Eqn. 2.3. This load was used to calculate the compressive axial stress when forming the draw-bead, σ_{DB}. The factor of safety was defined as:

$$\text{Factor of Safety} = \sigma_y / \sigma_{DB} \qquad (2.19)$$

The calculated values for the factor of safety for the different pipe schedules for case 1 analysis (Eqn. 2.17) are shown in Table 2.6:

Table 2.6: Calculated values for factor of safety σ_y / σ_{DB}, for case 1, L=32 in

Nominal Size, in	Schedule	Compressive Axial Stress when forming the draw-bead (σ_{DB}) for P_F= 4200_lbf, ksi	Factor of Safety, σ_y / σ_{DB}
1	10	10.17	1.69
1	40	8.50	2.02
1	80	6.57	2.62
1.5	10	6.85	2.51
1.5	40	5.25	3.27
1.5	80	3.93	4.37
2	**10**	**5.41**	**3.18**
2	**40**	**3.91**	**4.40**
2	**80**	**2.84**	**6.05**
2.5	10	4.04	4.25
2.5	40	2.46	6.98
2.5	80	1.86	9.23

2.0 in. pipe schedule has conservative safety factor of 3 as a minimum that can be achieved, for schedule 10, up to a safety factor of 6 for schedule 80. Nominal size 2.5 in. pipe is just too large to fit the furnace overall dimensions. However, having these calculated values provided a useful insight as for the gains which can be accomplished by going to the next pipe size. It was not necessary to solve case 2 analysis (Eqn. 2.18), since the 2.0 in. pipe schedule at the extreme length of L=32 in. (case 1) would not fail under buckling before yielding.

2.5.4. Load Analysis of Imperfect Columns

It was a given from the previous analysis that the applied loads passed through the centroid of the cross sections, and that the centroids of all cross sections were on a straight axis. However, this is not the case in real life. Manufacturing tolerances can play a significant role in defining the offset between the axis of the axial loads and the centroids of the cross sections [9].

This effect is referred to in the literature as the impact of eccentricity in loading on buckling [9]. In this case, the load is at a distance *e* from the centroid of the cross section (Figure 2.11).

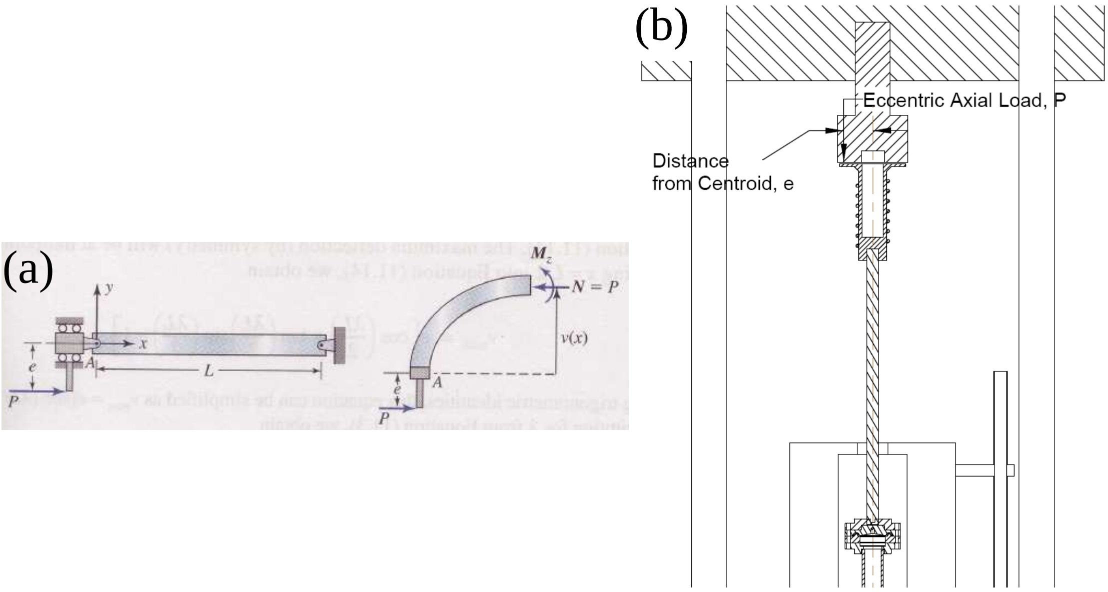


Figure 2.11: (a) Loading components of a eccentrically loaded beam, from [9]; and (b) Representation of the loading column being loaded eccentrically.

Because the axial load P is offset from the centroid of the cross section, the maximum normal stress has a new component, a bending stress [9]:

$$\sigma_{\max} = \frac{P}{A} + \frac{M_{\max} \cdot y_{\max}}{I} \tag{2.20}$$

Ideal case + Bending Stress

Since the maximum bending will be at the midpoint of the column [9], the equation for the maximum normal stress σ_{max} due to the force P applied at an offset distance *e* from the centroid of the cross section can be resolved as [9]:

$$\sigma_{\max} = \frac{P}{A}\left[1 + \frac{e \cdot c}{r^2} \cdot \sec\left(\frac{L_{eff}}{2 \cdot r} \cdot \sqrt{\frac{P}{E \cdot A}}\right)\right] \tag{2.21}$$

Where: $c = y_{max}$ = maximum distance from the buckling (bending) axis to a point on the cross section.

Using c = (pipe outer diameter (OD)) / 2

Applying this analysis to the three different schedules for 2.0 in. nominal size:

$$c = 1.187 \text{ in.} \tag{2.22}$$

and ranging the offset of the loading, *e*, from 0 in. (perfect column) to 0.300 in, the factor of safety σ_y / σ_{MAX} decreased as shown in Figure 2.12:

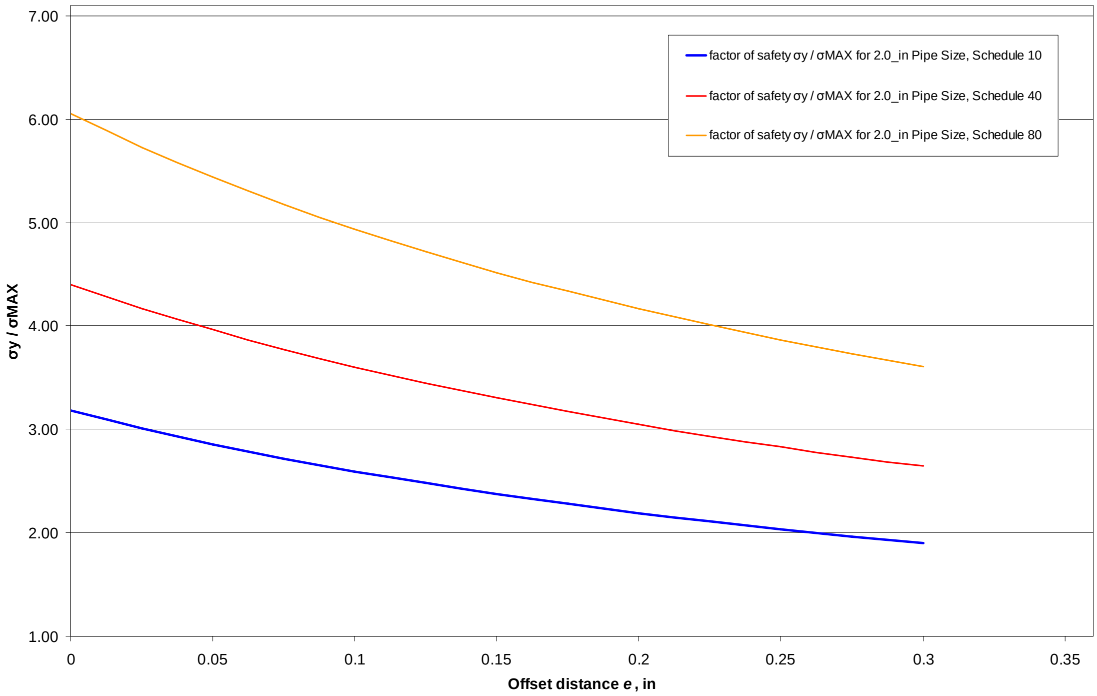


Figure 2.12: Factor of safety σ_y / σ_{MAX} for loading column analysis when load is offset by a distance *e*. Analysis for 2.0 in. pipe for the different schedules available according to ASTM B-167, for case 1, L=32 in.

The results obtained from the imperfect column analysis show the importance of a proper mating between the die-rings. Improper alignment between die-rings can not only be catastrophic for the die-rings themselves, it can also develop permanent plastic deformation between components in the loading columns.

2.5.5. Gas-Pressure Lines

The following factors were used to define the gas pressure system within the GPBF apparatus:

- The safety requirements;
- Pressure rating;
- Temperature rating;
- Tubing surface finish, material, hardness and wall thickness.

Since it was required to have at least one layer of protection in the hot zone between the gas-pressure lines and the user, the gas-pressure line was located inside the loading column. Having the gas-pressure line inside the loading column pipe, a potential rupture of the gas-pressure line within the hot zone could be contained by the structure. The minimum forming pressure required was 200 psi. The gas-pressure lines will have to sustain 400 psi with a factor of safety of 4 at its minimum.

Using the recommended values from Swagelok®, Appendix A, for pressure ratings 400 psi or above at 1000°F, fully annealed, high-quality (type 304, 316, etc.) (seamless or welded and drawn) stainless steel hydraulic tubing is the best option. A factor of 0.75, see Appendix A, will be introduced to compensate the pressure rating for temperature. For a wall thickness of 0.035 in., ¼ in. OD pipe has a pressure rating of 5100 psi. Since the gas-pressure line must be within the loading column, one end must exit at the top end of the loading column, requiring a 90 degree bend. Having chosen a small pipe diameter allowed this bend to be easily produced.

Swagelok® tube fitting ends are rated to the working pressure of the tubing. All Swagelok® tube fittings within the heating zone will be made out of fully annealed, high-quality stainless steel 316. All Swagelok® tube fittings will be for ¼ in. OD pipe.

The overall pressure rating at 1000°F will be 5100psi x 0.75 = 3825 psi, giving a factor a safety of 9.

Appendix B shows the exploded view of all gas-pressure line components with the required part numbers (P/Ns).

2.5.6. Thermal Expansion and Thermal Conductivity of Components within the Hot Zone

It is critical to understand and define the effects of heat on the components directly exposed to the heat coming from the furnace during the heating cycle and during the experiment. Thermal expansion will primarily affect the distance between the die-rings as components expand in the direction of loading. On the other hand, by the principles of thermal conductivity, heat will travel from the heated zone of the loading-column pipes to the cold zone at each heat-exchanger. By the same principles, heat will also travel in the same direction in the measuring-rod and the gas-pressure line.

As the furnace heats each loading-column pipe, they get closer to the desired temperature. By the principle of radiation, heat leaving the inside walls of the loading-column pipes will heat the measuring-rod and the top gas-pressure line attached to the top die-ring. As the system reaches steady state, all thermal gradients become constant. Components inside the loading-column will reach the required temperature. To verify this, a K-type thermocouple will be located inside one of the loading-column pipes. This thermocouple will determine the temperature of the air trapped inside one of the loading-column pipes (Figure 2.13).

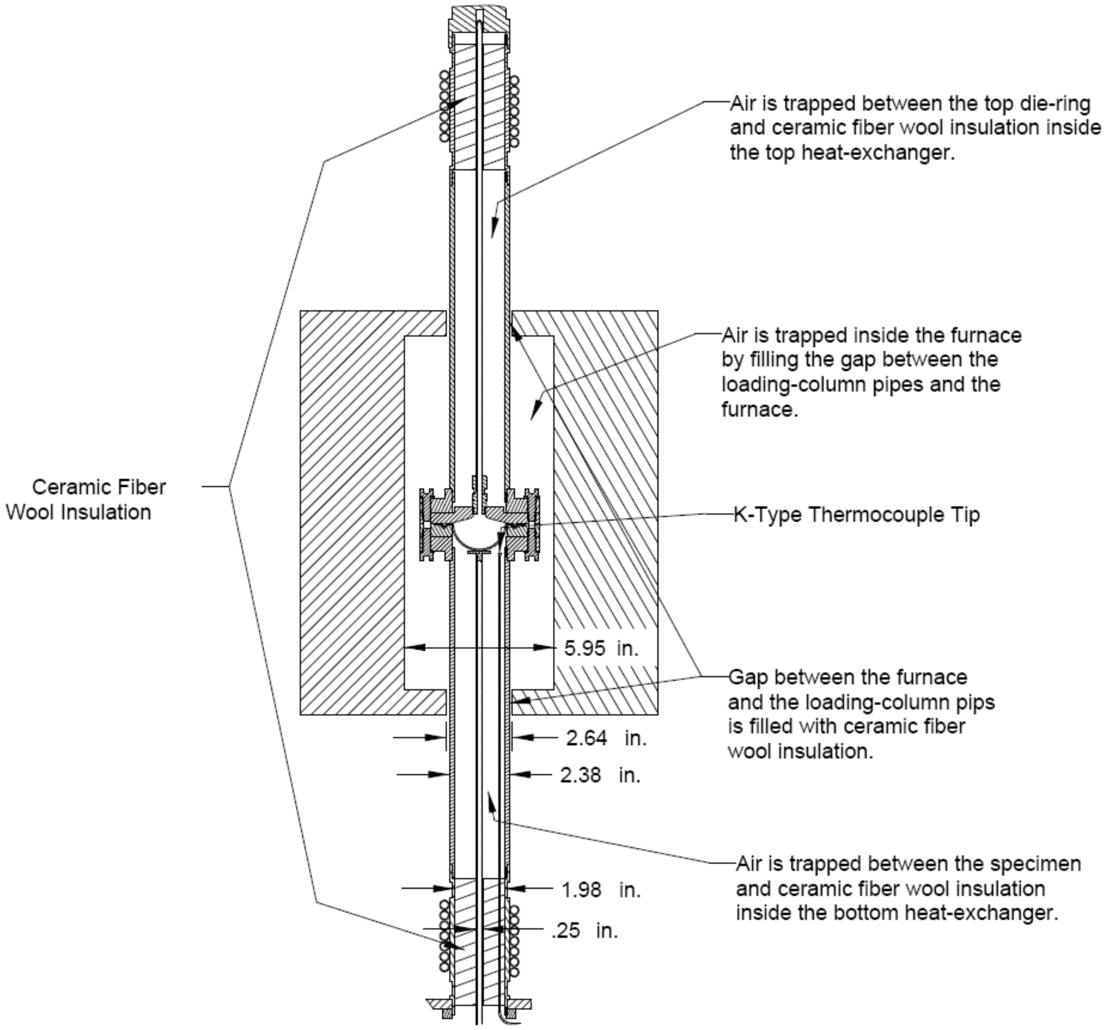


Figure 2.13: Cross section showing components inside loading column.

The design will initially incorporate heat-exchangers attached to the loading-column pipes only. It is assumed that the radiated heat from the loading-column pipes is the main source of heat into the components inside the loading-column pipes. The temperature gradient of the components inside the loading-column pipes and the loading-column pipes will be very similar. To minimize the effects of thermal expansion on dome height measurements, the loading column pipes, the measuring-rod, and the top gas-pressure line will have very similar lengths and they all will be constructed of the same material, annealed stainless steel 316.

The change in length between the loading-column pipes and the components inside them due to thermal expansion in the direction of loading will be nearly identical. All the components just mentioned will equally expand in the direction of loading. To validate this assumption, a set of experiments will be conducted to test this assumption. If the difference in thermal expansion is noticeable, i.e., above 0.005 in., further research will be conducted to correct any effect on dome-height measurements.

2.6. COMPLETION OF FINAL MODEL BY COMPUTER AID DESIGN (CAD)

All the calculated values for the different parameters on previous chapters proved to be the absolute limits by which buckling, yielding, or damage at interfaces can occur. The final design did not reach the maximum lengths that can fit the servo-hydraulic unit. The loading-columns consisted of one piece directly attached to the die holder, and a second piece, the heat-exchangers, directly attached to the structure of the servo-hydraulic unit. The heat-exchanger is another piece of 2.0 in. pipe, austenitic stainless steel 316, wrapped around a copper coil. The copper coil's diameter is slightly smaller than the 2.0 in. nominal pipe size, making the coil spring-loaded against the surface of the pipe. The diameter of the pipe used to make the copper coil was 3/8 in. To increase the contact surface between the copper coil and the pipe, a high K thermal conductive epoxy was used to fill the gaps between each wound of the coil and the 2.0 in. pipe.

The thermal conductive epoxy used was P/N 50-3100 HIGH THERMAL K HEAT TRANSFER EPOXY RESIN, in conjunction with CATALYST 190. The manufacturer of the epoxy and the resin is Epoxies, Etc...®. See Appendix D for Material Safety Data Sheet (MSDS) and Appendix E for mechanical properties and preparation instructions.

The approach taken for the amount of heat the heat exchangers could take was simple. Each heat-exchanger will have an almost infinite source of cold water that will run at a fairly fast speed through each coil. Cold water would flow through the coils. The gas-pressure blow-forming apparatus will be slowly heated, while temperature of the coil will be monitored. If the heat-exchanger experiences trouble maintaining the cooling requirements, the flow-rate of the water reservoir would have to be increased by means of an external pump.

The heat-exchangers were a critical portion of the system, but it was only a safe mechanism to maintain at all cost components beyond the heat exchangers at room temperature. As long as they could perform and maintain their performance, it was acceptable to not have data proving their validity. The design model could then be completed.

Figure 2.14 shows the GPBF apparatus mounted to the servo-hydraulic unit with the furnace in its permanent position. Figure 2.15 show the four subsystems composing the gas-pressure blow-forming apparatus: (A) the loading-column; (B) the clamping mechanism; (C) the mechanism for measuring dome height as a function of time; and (D) the gas-pressure lines for gas-pressure forming.

See Appendix B for the full exploded view of components, bill of materials (BOM) of all components, and the detailed drawings for the die-rings, the die-holders, and the loading-column pipes.

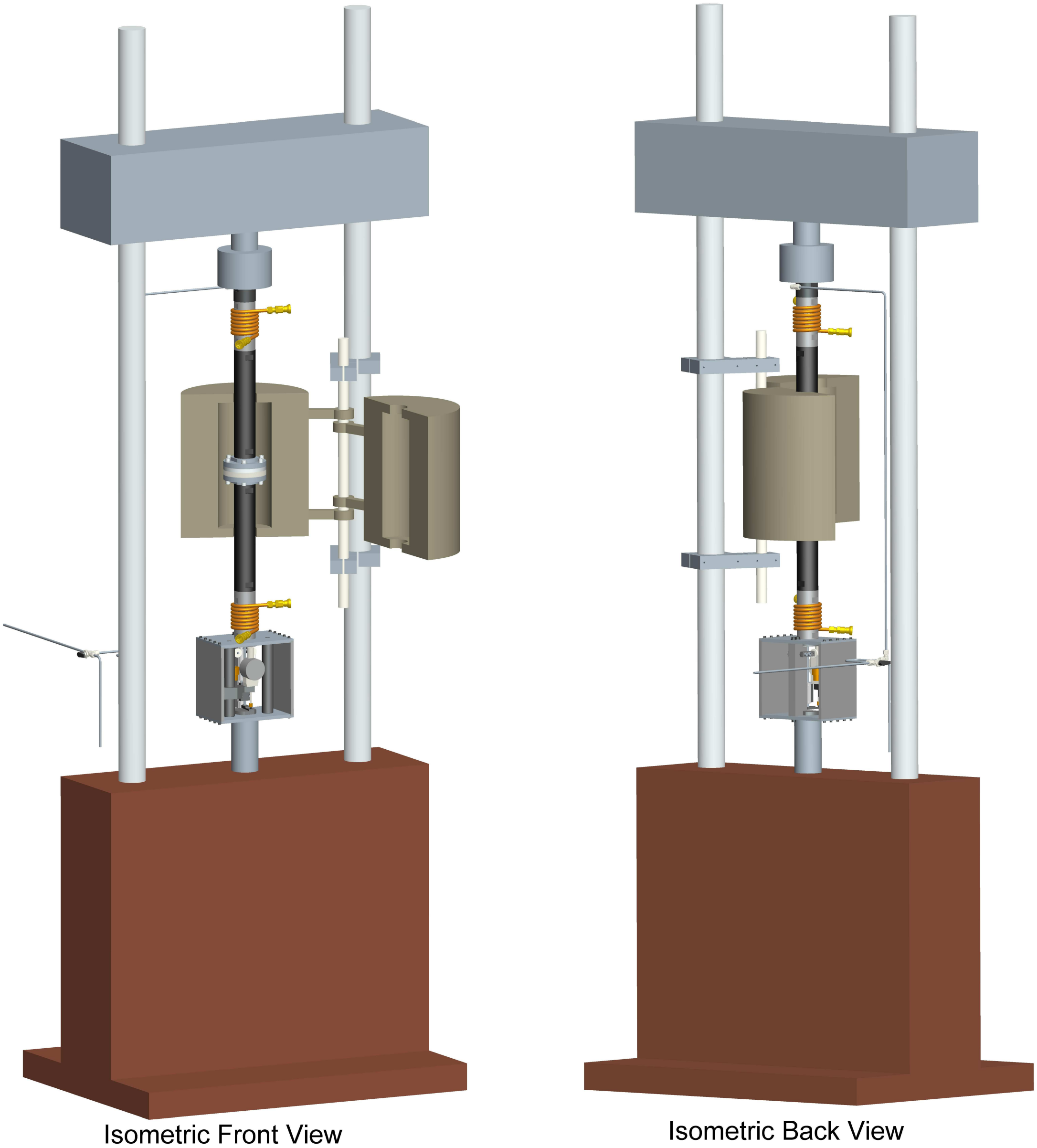


Figure 2.14: GPBF apparatus and furnace mounted in the servo-hydraulic unit.

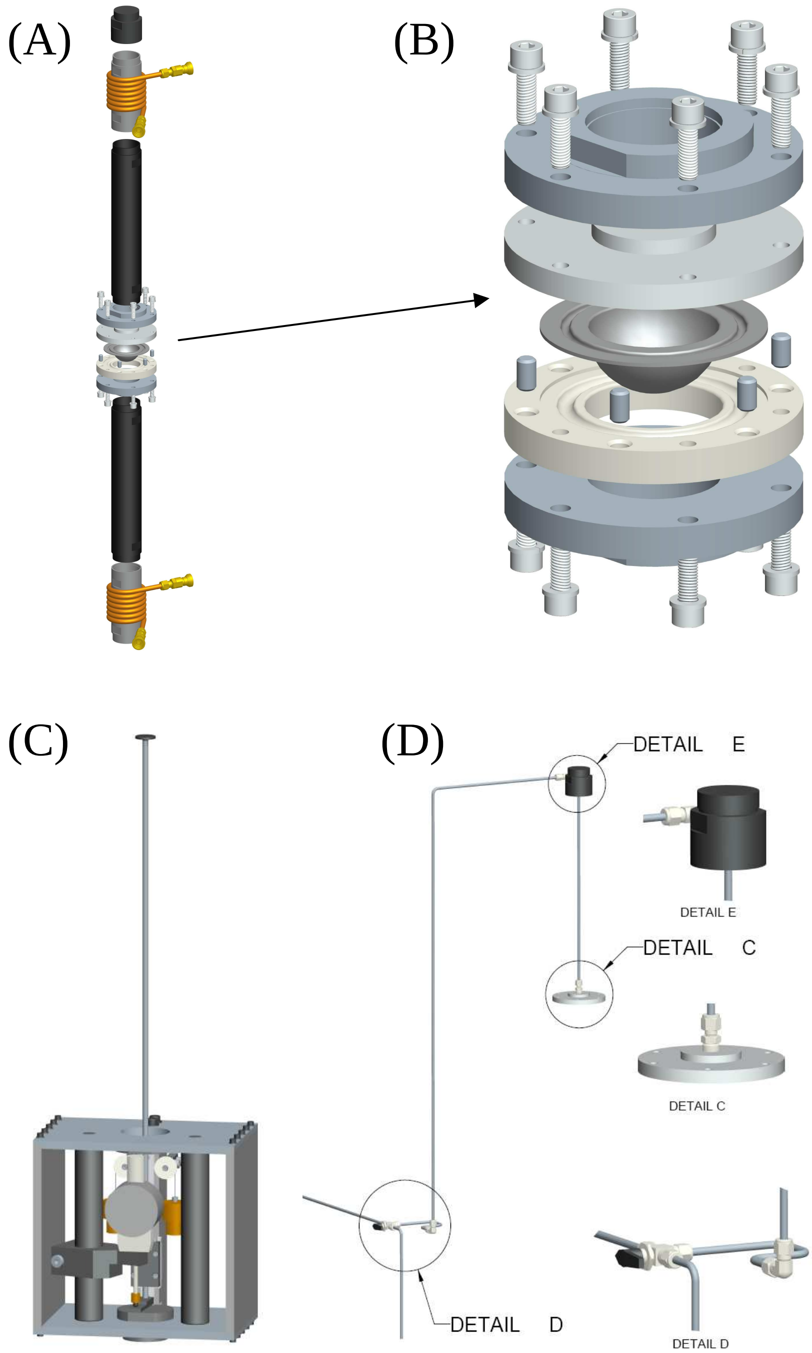


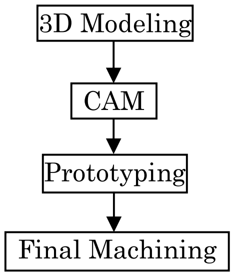
Figure 2.15: The four subsystems composing the GPBF apparatus: (A) the loading-column; (B) the clamping mechanism; (C) the mechanism for measuring dome height as a function of time; and (D) the gas-pressure lines for gas-pressure forming.

Chapter 3: Validation of Design

3.1. CONSTRUCTION OF GAS-PRESSURE BLOW-FORMING APPARATUS ACCORDING TO FINAL MODEL

3.1.1. Machining Process

The following steps were taken to complete the components required to be machined for the GPBF apparatus:



The final design from Chapter 2.6 describes all four subsystems of the apparatus. Only the components required to be machined were taken to the computer aided manufacturing (CAM) software. CAM software allows the user to generate the computer numerical control (CNC) code required by a CNC mill to machine the parts. Traditionally, 3D models are used to generate the drawings used by professional machinists as a reference to machine the parts. Using a CNC mill for some of the more intricate parts of the design provided two advantages over traditional machining:

-It allowed the generation of prototype pieces in soft materials, like high-density foam. These prototypes were completed in 1/10th the time it would have taken to machine the actual parts. The prototypes gave valuable insight into the design process;

-Second, the machining of repeated features, such as the threaded interface between the components of the loading-column. Machining the threading of pipe-ends by CNC reduced tolerance issues substantially.

One critical aspect of the design was maintaining tight tolerances, as explained in Chapter 2.5.4. The design required an interface between die-holders, loading columns and heat-exchangers to be concentric and square. Over 40 inches of piping had to be interfaced. Each pipe's end had to connect to another component, and each joint had to be exact and strong. The total tolerance build-up had to be maintained at the minimum possible. Using a CNC-mill for completion of the threaded interfaces at each end of the loading column components proved to deliver on all these requirements.

Figure 3.1 shows the steps taken to complete the bottom die-ring. First, a 3D model was completed with all necessary features. This same model was then taken to the CAM software, and a virtual CNC-mill generated the machining operations. This same program generated the numerical code required for the actual CNC-mill. The prototype of each die was made in a soft material. Once the design of each component was finalized, the die-rings were machined in the actual material. Figure 3.2 shows the steps taken to complete the top die-ring.

The following are the software packages, the material selection, and the equipment used for the generation and completion of the different steps of the machining process:

- Pro|ENGINEER® Wildfire, Release Wildfire 3.0 for the generation of the 3D models;
- Mastercam® X, Release X2 for the generation of the virtual machining operation and the CNC code used by the CNC mill;
- INCONEL® alloy 600 for the fabrication of the die-rings, the die-holders, and the measuring-rod tip;
- Austenitic stainless steel 316 for the fabrication of all the pipes that conform the loading column, the core pipe of the heat-exchangers, the gas-pressure

lines, the bolts that hold the die-rings to the die-holders, and the measuring-rod;

- Austenitic stainless steel 304 for the fabrication of components outside the heating zone such as the walls of the bottom enclosure, the sliding-rail holder, the alignment-pins, bolts outside the heating zone, and the pulley holders;
- HAAS® CNC VMC VERTICAL SPINDLE Model VF-1 for all CNC machined operations.

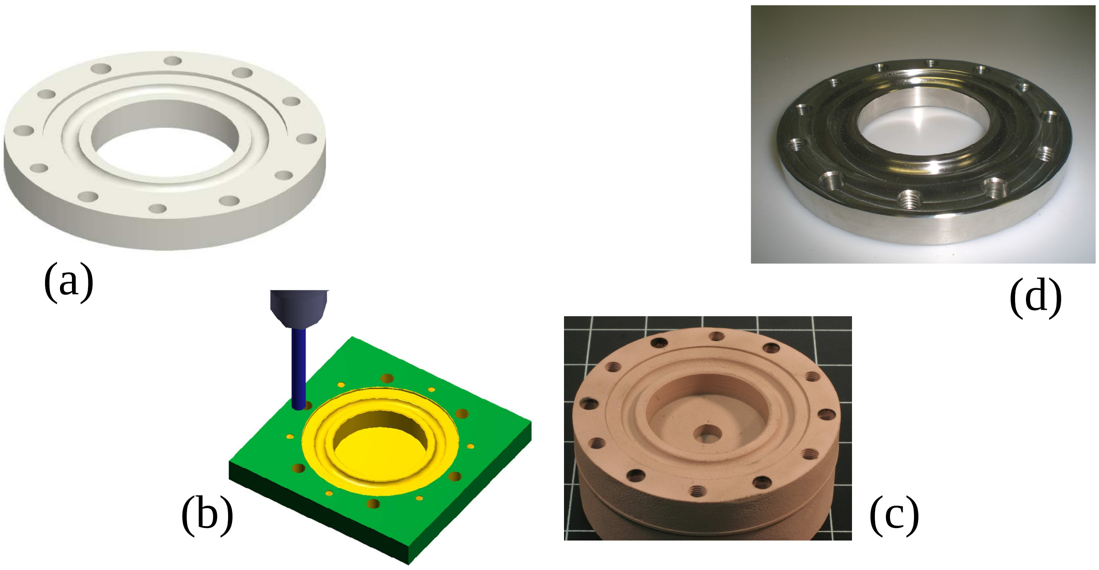


Figure 3.1: Steps taken to complete bottom die-ring: (a) first, 3D model was completed with all its features; (b) same model was taken to the CAM software, and a virtual CNC-mill generated the machining operations; (c) CNC code was generated and a prototype was made in a soft material (high-density foam); (d) once the design was proven correct, the machining of the actual die was completed.

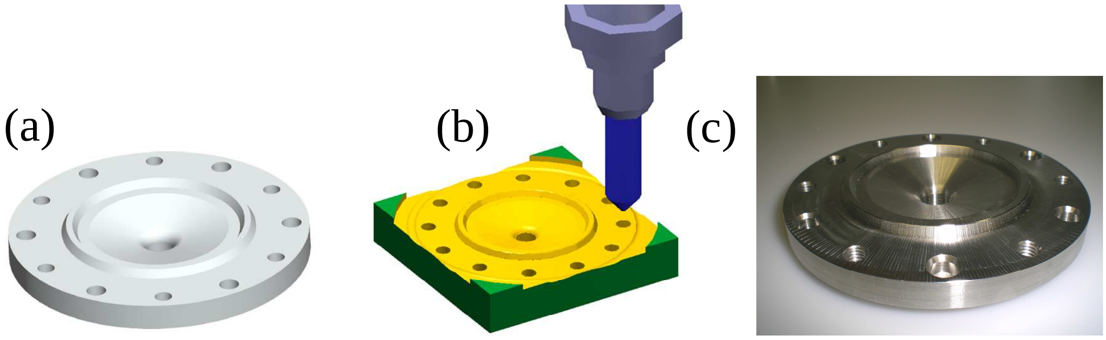


Figure 3.2: Steps taken to complete top die-ring: (a) 3D model; (b) CNC virtual machining operation; and (c) machining of part in the actual material.

Thread milling is a very intricate process. The mating of male and female threaded components is very dependent of the material properties, the routines used for the thread machining operations and the required fit between the threads. Threaded prototypes had to be accomplished in the same material used for the final product. Only by using the same material was it possible to generate the required tolerances for proper mating.

The end result was a threaded interface between components capable of maintain a 0.003 in. tolerance between joint. Traditional pipe threading requires a clearance at the end of the thread so both interfaces can thread end-to-end. This prevents the thread of one component, the male threaded piece, meeting a location on the female piece without sufficient mating thread. One problem of using this approach is that the alignment between the threaded components depends solely on the clearance and alignment gained between the threads. Controlling tolerance build-up to within required limits by this method is not possible. In the final design, the threaded interface design for the loading column was made so that, instead of having clearance at the end of the thread, a lip of a slightly larger diameter was left at the end of each thread. Because the threads were produced in a CNC-mill, it was possible to accurately produce the exact clearance required by the threads, while an alignment feature at the end of the threaded pieces controlled tolerance build-up.

Looking at the cross-section of the interface, one can see that this lip maintains alignment between components, regardless of the looseness of the threads. This same lip provides an end-to-end mating interface, providing effective alignment and efficient transfer of compressive loads. Figure 3.3 shows the cross-section of the threaded interface design.

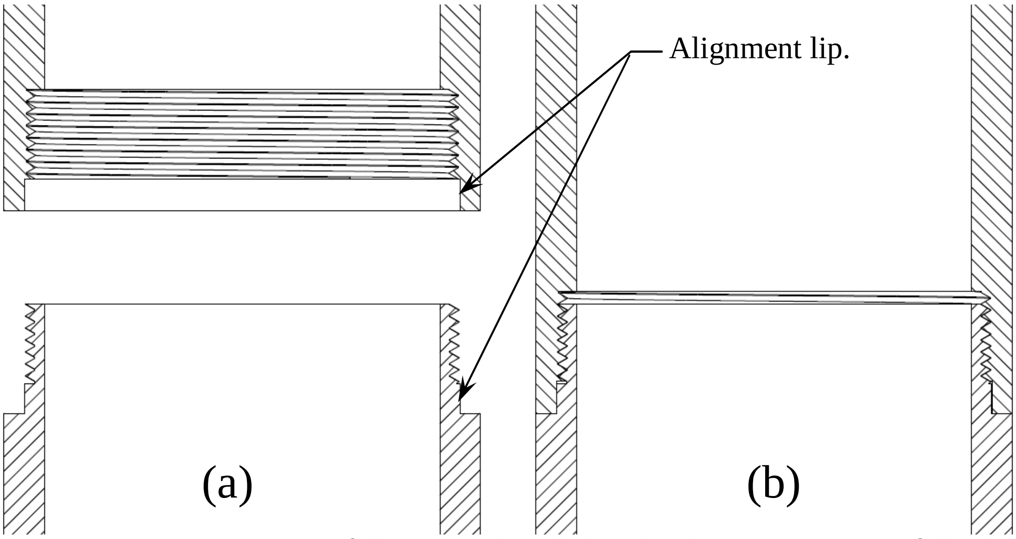


Figure 3.3: (a) cross-section of the pipes threaded-ends; (b) cross-section of the threaded interface.

Figure 3.4 shows the components of the top loading-column assembly. The arrows show the direction of mating among components.

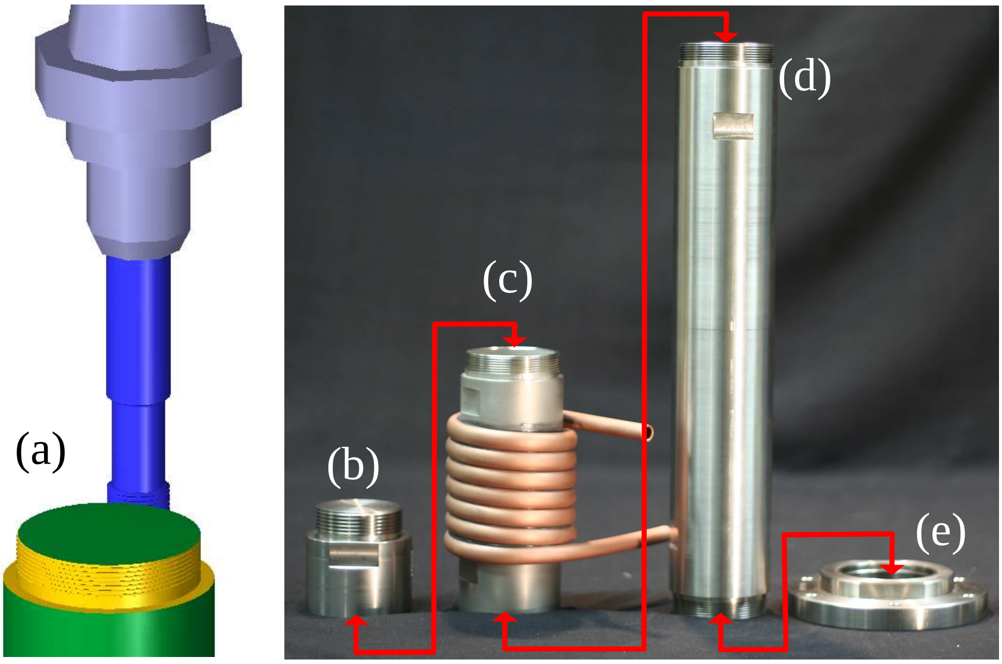


Figure 3.4: Top loading-column assembly: (a) virtual machining of threaded interface using CAM software. Threaded interface between components of the loading column: (b) load-cell thread adapter; (c) top heat-exchanger; (d) top loading-column pipe; (e) top die-holder. All interfaces (red lines) were machined using the same machining code, reducing tolerance build-up to a minimum.

3.1.2. Assembly of Subsystems

Some subsystems within the assembly process were put together separately to facilitate final assembly. The top loading-column assembly (Figure 3.5) and the sliding-rail assembly were assembled and brought as single units into the assembly process.

The assembly of the top loading-column is explained by Figures 3.5 through 3.9.

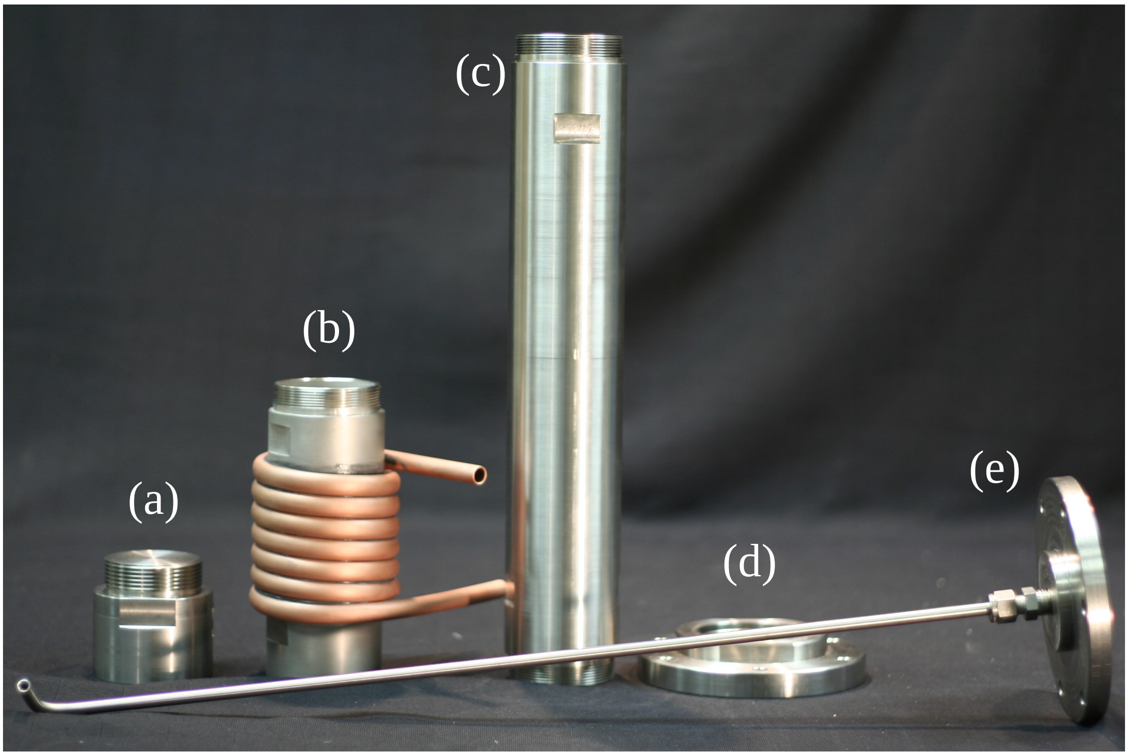


Figure 3.5: Top loading-column assembly: (a) load-cell thread adapter; (b) heat-exchanger; (c) loading-column main pipe; (d) die-holder; and (e) top die-ring with air-sealed fitting and pipe for the pressurizing gas used for bulge forming.

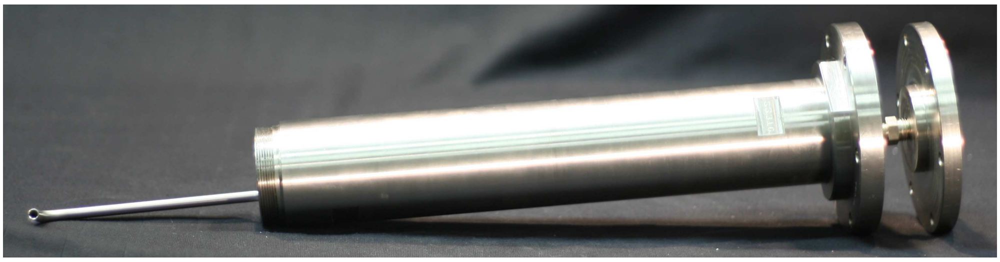


Figure 3.6: Top die-holder is threaded to the loading-column main pipe.
The pipe used for the pressurizing gas is slid through.

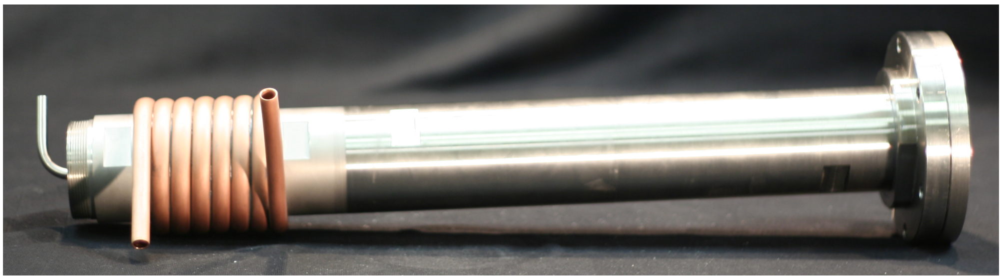


Figure 3.7: Top heat-exchanger is threaded to the loading-column main pipe.

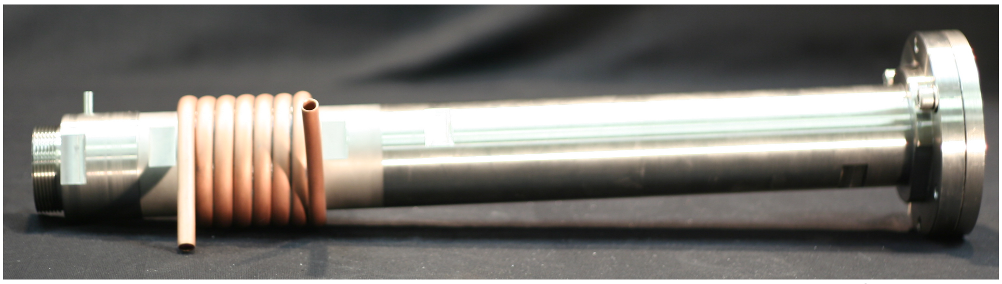


Figure 3.8: Load-cell thread adapter slides through the round bend of the pressurizing gas pipe. It is then threaded to the heat-exchanger. During this operation, the pipe for the pressurizing gas rotates along with the top-die ring inside the top loading-column pipe.

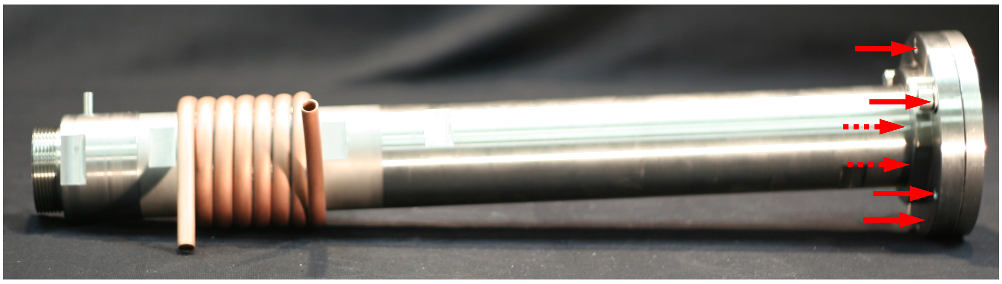


Figure 3.9: A Six-bolt pattern attaches the top die-holder to the top die-ring. The top die-ring is no longer allowed to spin.

The sliding rail assembly was the second subsystem to be pre-assembled. The sliding-rail assembly is part of the system to capture dome-peak displacement (Figure 3.10). The system to capture dome-peak displacement is composed of: (a) the enclosure; (b) the sliding-rail assembly; and (c) the micrometer measuring assembly. Only the sliding rail assembly is explained in this section.

Appendix B3 shows the components of the sliding-rail assembly. First, the sliding-rail is mounted to the sliding-rail holder. Once that is completed, the measuring-rod holder can then be bolted on top of the sliding cart (part of the sliding rail). The pulleys are bolted to the pulley-holders. Pulley-holders are then attached to the sliding-rail holder. The measuring-rod (Figure 3.10(a)) is attached to the system later in the assembly process. The measuring-rod slides in the measuring-rod holder and socket screws keep its location once calibration is finalized.

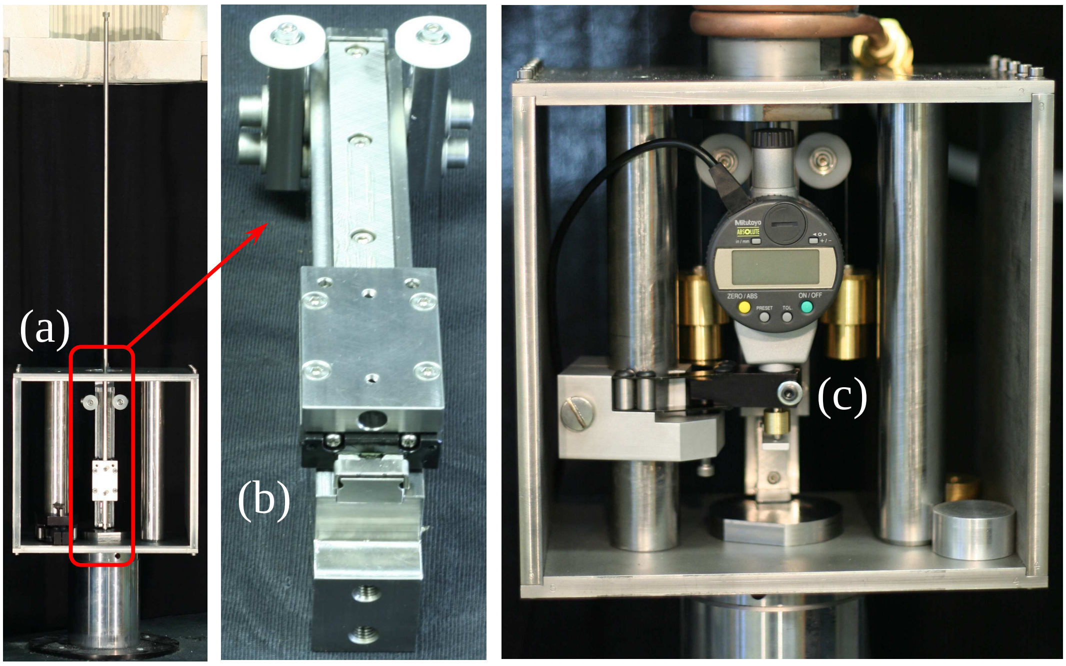


Figure 3.10: System to capture dome-peak displacement: (a) the enclosure; (b) the sliding-rail assembly; and (c) the micrometer measuring assembly.
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See Appendix C for the datasheets and part numbers (P/Ns) for the micrometer, the micrometer’s mount, the computer interface, the sliding rail and the pulleys of the sliding-rail assembly.

Dome peak displacement is captured by the measuring-rod. The micrometer is in direct contact with the measuring-rod (Figure 3.10(c)). As the specimen is bulge-formed, the measuring-rod is moved downward, displacing the measuring-rod holder by an equal amount. The micrometer’s stem rests on a flat piece directly attached to the lower end of the measuring-rod holder. As the measuring-rod moves downward, the micrometer records its displacement downward. The micrometer provides a continuous digital readout through a serial interface. A computer captures the displacement data generated by the micrometer. Finally, the computer stamps a time on every data point. From these data, a plot of dome-height as a function of time can be made, from the time the specimen is flat, just before forming, to the point of fracture, typically at the peak of the bulge-formed specimen. At this point, pressurizing gas leaks through the crack of the specimen and the experiment is stopped.

Because the sheet is formed downward, gravity makes all the components attached to the sliding-rail slide down. A counter-weight balancing system is attached to the sliding rail (Figure 3.11) to compensate the forces generated by the weight of the components attached to the cart of the sliding-rail. Two pulleys mounted on ball-bearings allow brass weights counter-balance the sliding-rail weight. Nylon filaments have one end attached the measuring-rod holder and the other end to the each brass weight.

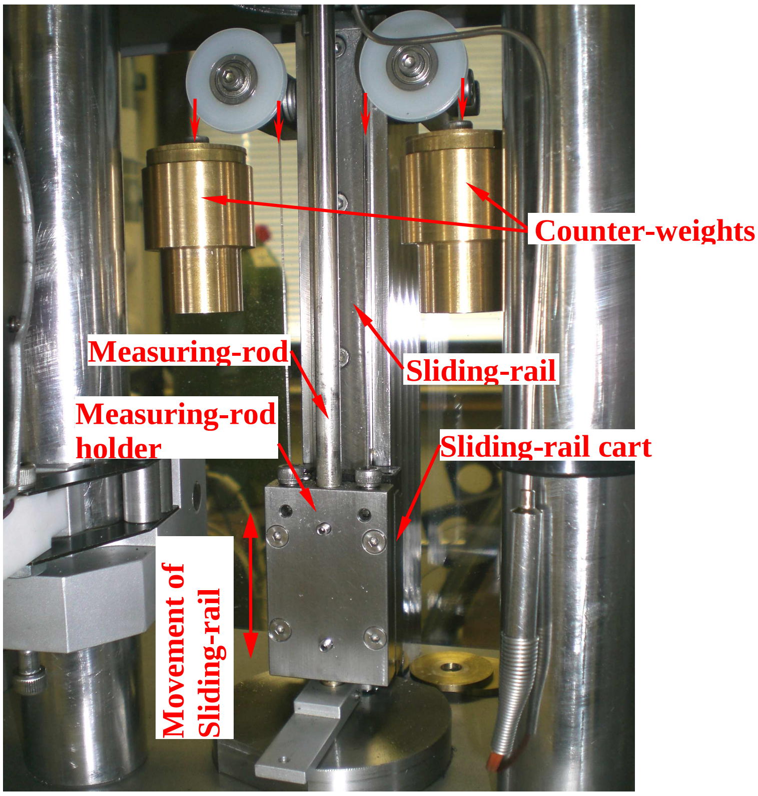


Figure 3.11: Counter-weight balancing system. Counter-weights are attached to the measuring-rod holder by nylon strings.

The counter-weight balancing system provides an almost weight-free sliding measuring system. However, overall, the system is not designed to be an absolutely weight free system, some upward force is necessary to keep the flat at the end of the measuring-rod in firm contact with the sheet during forming. The brass weights of the counter-weight balancing system were calibrated to provide a small contact force and to overcome most sliding friction. However, the drag force of dynamic friction from lubricant applied to the sliding rail is larger than the force balanced of the weights. Thus, there is no risk of the slide drifting on its own.

Because the counter-weight balancing system is designed to take care of constant forces, no dampeners or springs could be used in the system without disturbing the almost weight-free sliding movement. The internal mechanisms of micrometers, however, have a spring and a dampener, to make its movement smooth and retractable. The introduction of a spring into the overall balance would have severely affected performance. A counter force from another spring of the same spring constant would have been necessary. To alleviate this problem, the spring inside the micrometer was removed. Since the micrometer for this particular application captures the displacement of the sliding-rod as it moves downward, an extra weight on the tip of the micrometer's stem was added. This keeps the micrometer's stem in contact with the measuring-rod assembly as it moves during forming of the dome.

There was concern as to whether the micrometers stem would keep contact with the measuring-rod assembly. If there was no proof of constant contact between the micrometers stem and the measuring-rod, one could not know if the data captured by the micrometers stem at one time is correlated to the displacement of the sliding-rod as the specimen is formed. To solve this uncertainty, an electrical continuity test was added between the micrometer's stem and the sliding-rod assembly. If the sliding-rod assembly happens to slide down at a faster rate than the micrometer's stem can follow it, the electrical continuity test will immediately record an open circuit, and any data points captured during those intervals would be discarded. Fortunately, the strain rates at which experiments would be conducted do not require a fast movement of the sliding rod, but instead a very sensitive method for capturing the displacement.

3.1.3. Final Assembly Process

Figures 3.12 through 3.16 show the steps taken to assemble the gas-pressure blow-forming apparatus:

1. The system to capture dome-peak displacement is first installed to the ram of the servo-hydraulic. The bottom plate of this enclosure is attached to the ram by means of a two (2) in bolt, Figure 3.12(a).
2. Two 1¼ in. tower bars are located in place. These tower-bars are used to locate the micrometer measuring assembly system in placed and to provide structure to the enclosure, Figure 3.12(b).
3. The micrometer's mount is mounted to the left tower-bar, Figure 3.12(b).
4. All four walls of the enclosure are held in place but bolts are not fully tighten until all parts are located, Figure 313(a).
5. The sliding-rail assembly is integrated to the enclosure, Figure 3.13(b).
6. The measuring-rod is loaded to the measuring rod-holder, Figure 3.14(a).
7. The bottom heat-exchanger is mounted to the top-face of the enclosure, Figure 3.14(b).
8. The bottom loading-column sub-assembly is completed, Figure 3.15(a).

9. The top loading-column subassembly is attached to the load cell of the servo-hydraulic unit, Figure 3.15(b).

10. Finally, water is attached to the water fittings, Figure 3.16.

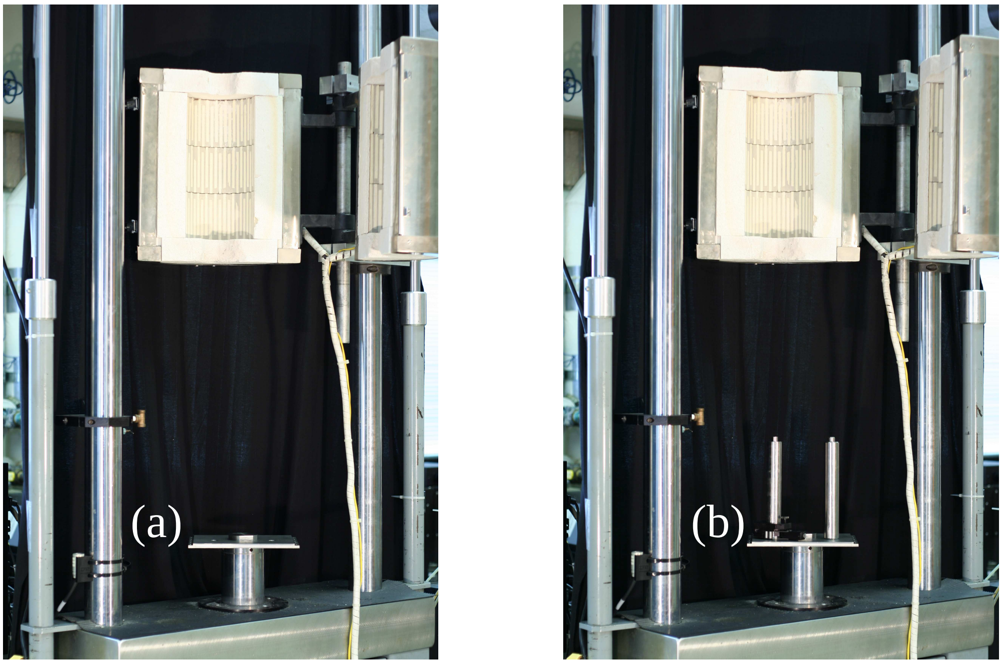


Figure 3.12: (a) bottom plate of enclosure is attached to the ram of the servo-hydraulic unit by a two (2) in. bolt; (b) columns in the enclosure are put in place. Holder for the micrometer is located in the left column.

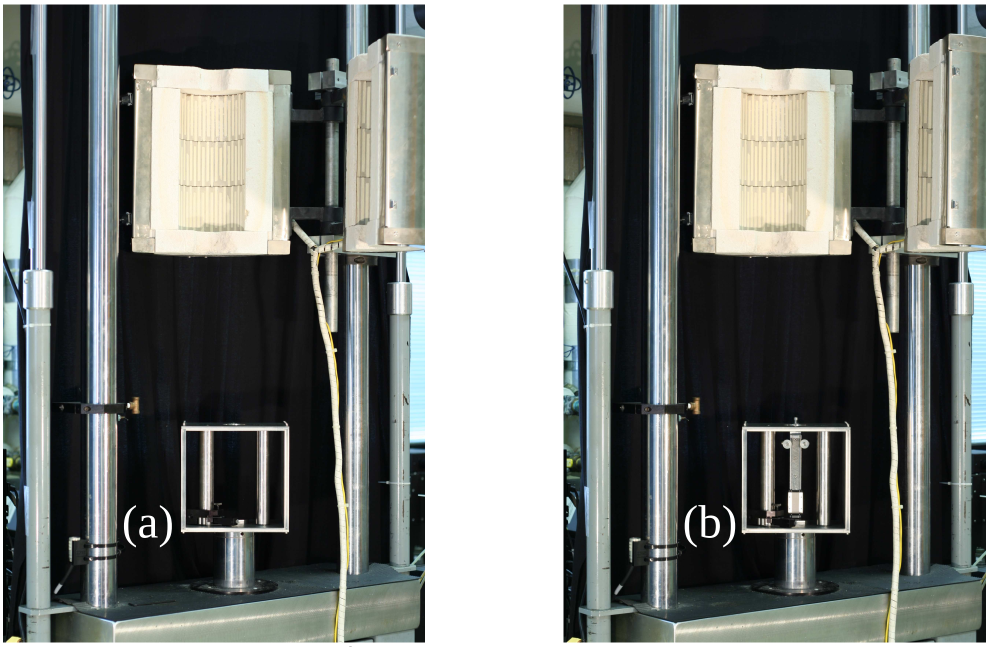


Figure 3.13: (a) top plate of enclosure is put in place but not bolted to the side plates; (b) sliding rail assembly is put in place. All bolts that attach the top plate to the side plates are gently tight. Alignment of the sliding rail will take place later in the process.

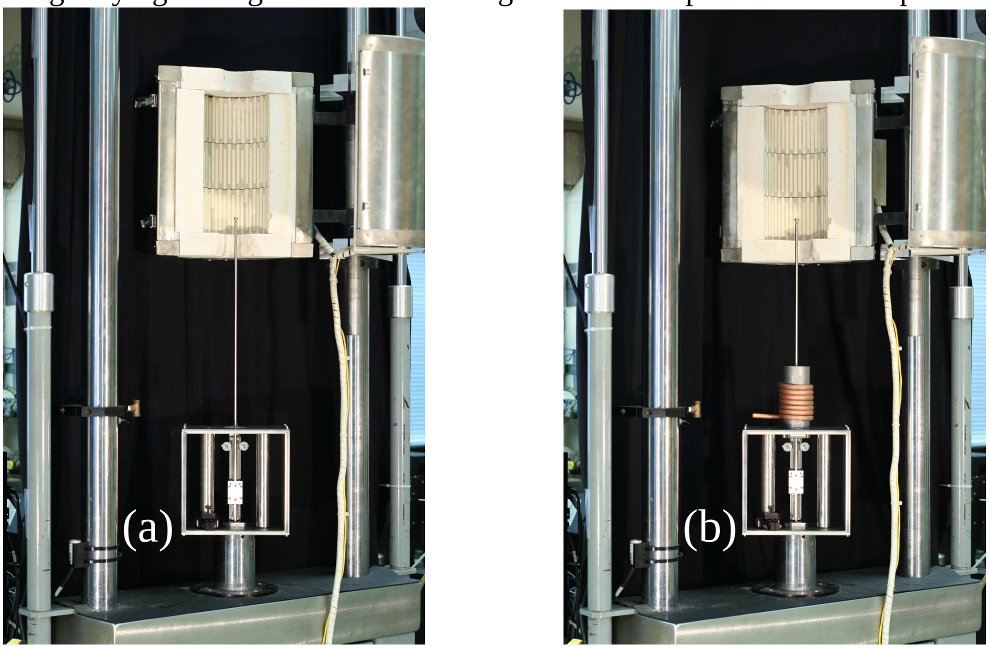


Figure 3.14: (a) measuring-rod is loaded to the measuring-rod holder. Its final position is to be calibrated later in the process; (b) heat-exchanger that attaches to the enclosure is located. The bottom heat-exchanger is tightened by the nut below the top plate of the enclosure.

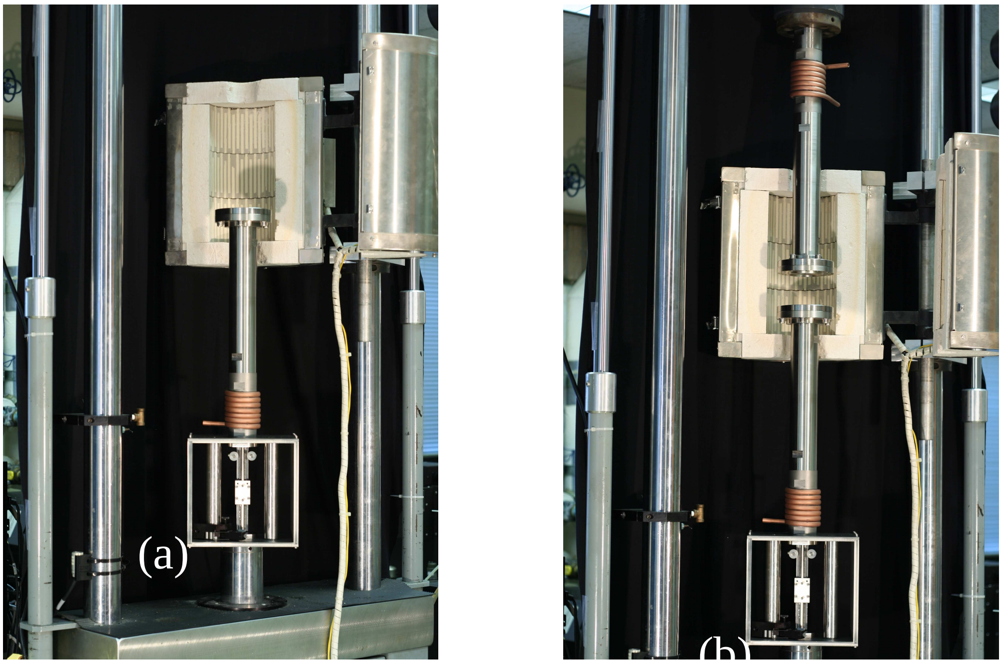


Figure 3.15: (a) bottom loading-column is assembled to the enclosure of the system to capture dome-peak displacement; (b) top loading-column assembly is threaded to the load cell on the top end of the servo-hydraulic unit.

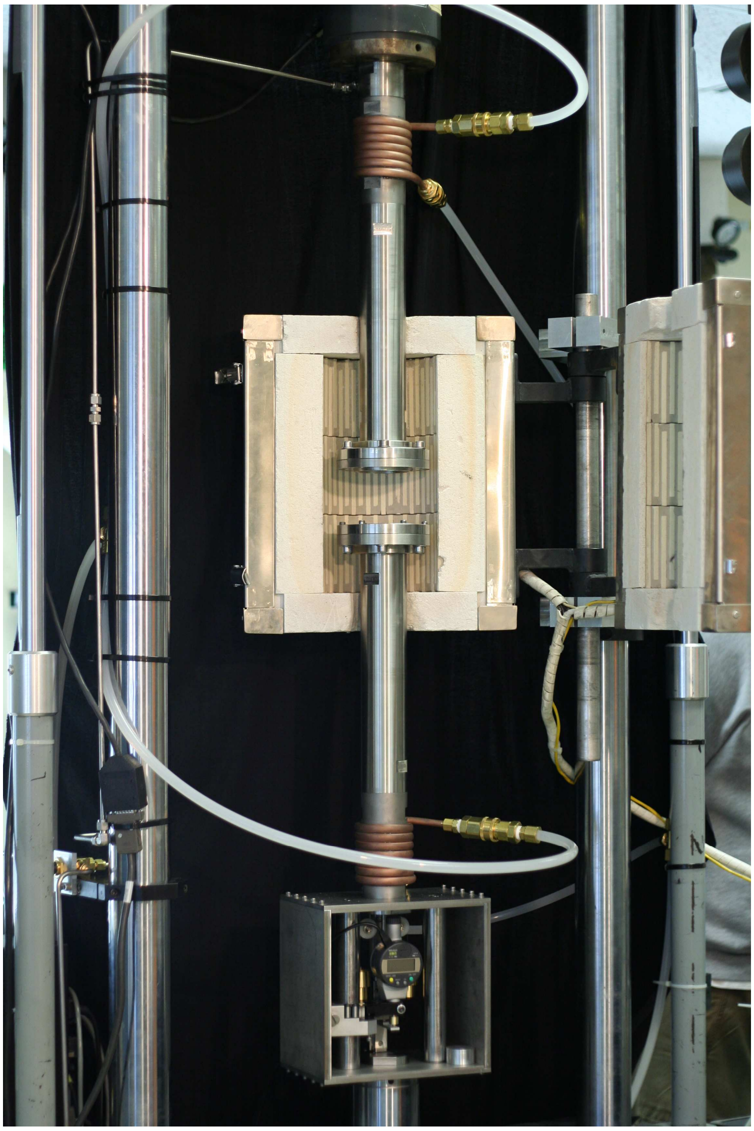


Figure 3.16: Water fittings are pressed into the end on the heat-exchangers. Air-sealed lines to the pressurizing gas for the forming process are connected. The required valves are also put in place.

3.2. Procedure Development to Run GPBF Apparatus

Besides the mechanical advantages of using the servo-hydraulic unit as the skeleton for the GPBF apparatus, the pre-built functions to conduct tensile and compressive tests proved to be a critical tool in the procedure setup. In the early stages of the project, the only reason the servo-hydraulic unit was chosen was to provide a rigid structure with a ram capable of providing the loading requirements as described in Chapter 2.5. However, the programmable functions proved to be as important as the loading capacity. Having a load-cell measuring the load exerted against dies and across all the members of the loading-column turned out to be extremely important in using the apparatus safely. Most important, safety limits could be easily set by programming the servo-hydraulic unit to shut off if loading values reach pre-set limit values.

Forming of the draw-bead is best conducted at the required temperature for bulge-forming (Chapter 2.5). The first approach used was to load the specimen in the bottom die-ring and heat all the components inside the furnace to the required temperature. Once temperature was achieved, the dies were closed at a slow loading rate (~5lbf/s) to the load required (2800 lbf according to the calculated values for a specimen 0.040 in. thick of aluminum alloy AA5182, Chapter 2.5.1). Allowing the components inside the furnace to reach the required temperature before clamping would prevent potential misfit from thermal expansions of the components of the loading-column during heating.

However, after the specimen was fully clamped and the measuring-rod was brought in contact with the specimen, a very small, constant, downward displacement of the specimen was observed. It was thought at first that the balancing weight setup was sliding slightly, or that some unexpected thermal expansion was changing the original length of the measuring-rod. However, the same material was used for the pipes of the loading-column and the measuring-rod. Moreover, the materials used for the construction of the dies and the tip of the measuring-rod where the same. Analysis shifted to whether the counter-weight balancing system was responsible for the small but noticeably drift seen at the beginning of experiment. To verify this, the measuring-rod was slightly lowered, 0.1 in, enough to separate the tip of the measuring-rod from the specimen, but still within the heated region so thermal expansion would not change The measuring-rod was then left static, balanced by the counter-weight balancing system. After 10 minutes, the value seen by the micrometer did not change.

The only potential cause left was the specimen itself. The procedure so far allowed all the components of the loading-column, the dome-height measuring system, and the specimen to heat together to the testing temperature and. The specimen was then clamped by the die- rings. Leaving the specimen to sit still on top of the bottom die-ring with no force applied in the periphery of the specimen during the heating cycle allowed the specimen to sag under its own weight. Furthermore, as the forming of the draw-bead occurred, the center of the specimen could sag even more. Basically, the testing started with a non-flat specimen. And since there was no pressurizing gas, it was very difficult to account for this phenomenon during testing. This miniature dome at the beginning of the experiment could significantly offset results, since it produced an initial offset in displacement that influenced the final results for dome-height as a function of time.

The clamping procedure was subsequently changed. Instead, during the heating cycle, the specimen would be clamped between the dies with a small load, much smaller than the one required to form the draw-bead, but significant enough to keep a load in the periphery of the specimen. The problem with this idea was maintaining a constant small load during the heating cycle, since components of the loading column were expanding and bringing the dies closer to each other, increasing the loading a significantly faster rates than wanted. To compensate for this, the servo-hydraulic unit was set to maintain a constant force rate of 2 lbf/s. The ram will adjust its movement up or down to maintain this slowly increasing. As components of the loading column begin to expand in the direction of loading, the ram will gently open the space between the dies maintaining the clamping within the desired range.

Because the specimen was now clamped between the die-rings, the measuring-rod could be brought to contact with the specimen during the heating cycle, reducing the uncertainty of thermal expansion. At this point the micrometer was zeroed, and the system was setup to capture any displacement. The results were outstanding. From the start of the heating cycle to the point where all components had reached steady-state temperature, the micrometer captured 0.0002 in. of displacement. From this experiment, it is clear that thermal expansion of the measuring rod is compensated by equal thermal expansion of the loading-column pipe. The experiment was starting out with a very flat specimen, and any dome height resulting from gas-pressure blow-forming could be captured and recorded with its unique timeframe stamped to it.

3.3. TESTING OF SPECIMENS UNDER QPF CONDITIONS

The first set of specimens tested came from a 1.5 mm (0.040 in) sheet of aluminum alloy AA5182. Figure 3.17(a) show the specimen just after the forming of the draw-bead. Figure 3.17(b) shows the first specimen formed under balanced biaxial bulge forming by the GPBF apparatus.

Figure 3.17: (a) specimen prior to gas-pressured blow-forming; (b) specimen formed at 450°C and a constant gas pressure of 40 psi.

Figure 3.18 shows 3 different specimens tested at a constant pressure of 40, 60, and 80 psi, each. All specimens were formed until rupture. Rupture of all three experiments happened at the peak of the dome, the point of balanced biaxial stress.

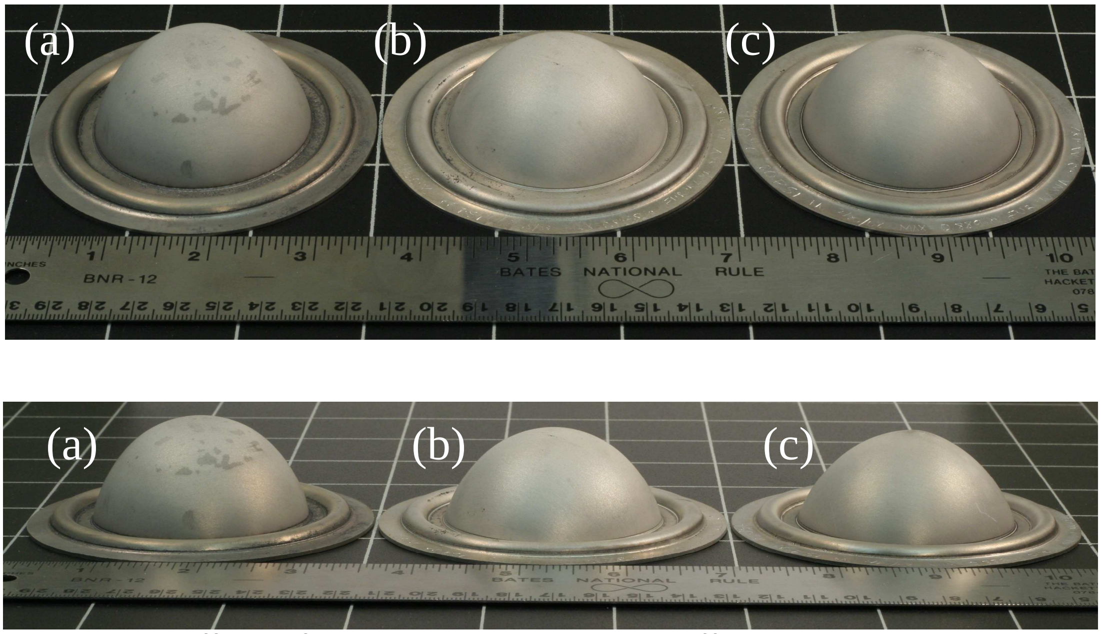


Figure 3.18: Different forming pressures result in different dome shapes and dome heights: (a) Specimen formed at 450°C and a constant gas pressure of 40 psi; (b) Specimen formed at 450°C and a constant gas pressure of 60 psi; (c) Specimen formed at 450°C and a constant gas pressure of 80 psi.

3.4. Validating Data Captured from Tested Specimens

Figure 3.19 shows the data captured during the forming of the specimens shown in Chapter 3.3. Figure 3.20 shows the work of Hector et al. [11] on "Simulating Elevated-Temperature Pneumatic Bulge Forming of AA5083," show the evolution of dome height normalized by die opening radius (h/R) from PAM-STAMP |2G™ and ABAQUS™ compared with experimental data collected at the conditions indicated.

To my knowledge, this is the first example of capturing data for real-time, in-situ displacement as a function of time. These data proceed from the initiation of dome forming to the point of rupture at the peak of the dome. The data captured follows the same pattern seen by previous experiments on aluminum alloy 5083 for similar temperatures and pressures, but obtained from multiple interrupted tests.

The equipment developed for this experiment has proven to consistently and continuously form a specimen by gas pressure forming while capturing in-situ real-time dome-peak displacement until specimen ruptures at the peak of the dome, the point of balanced biaxial stress. These are the first data for dome-height to be obtained in-situ for this type of test.

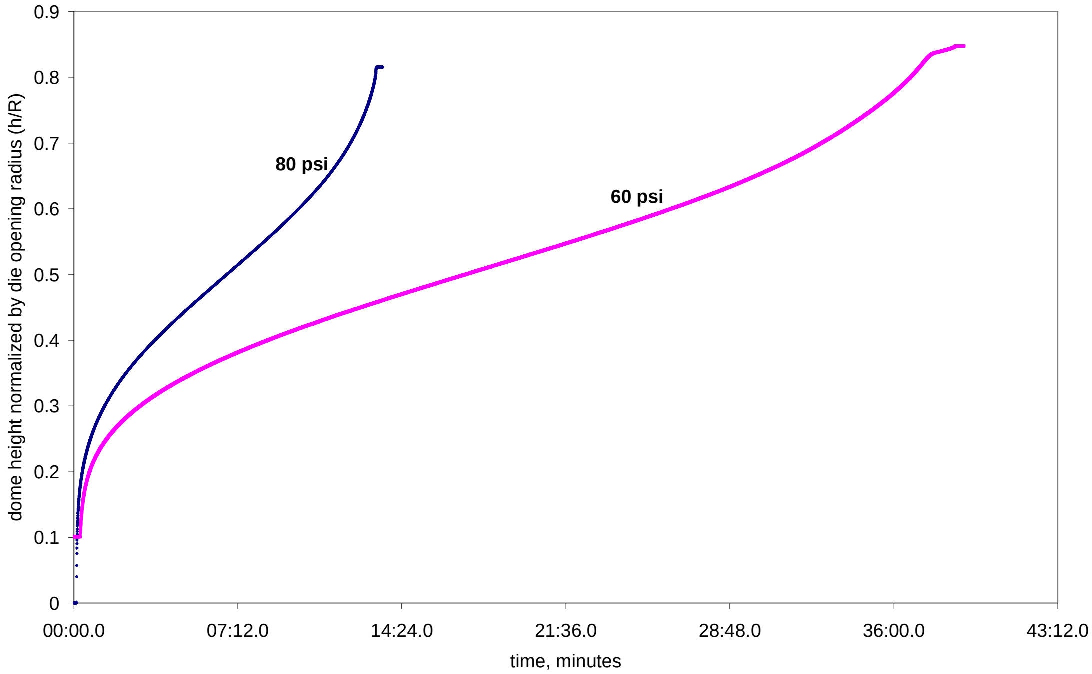


Figure 3.19: Data captured during the balanced biaxial bulge testing of 2 specimens at 450°C at the different pressures.

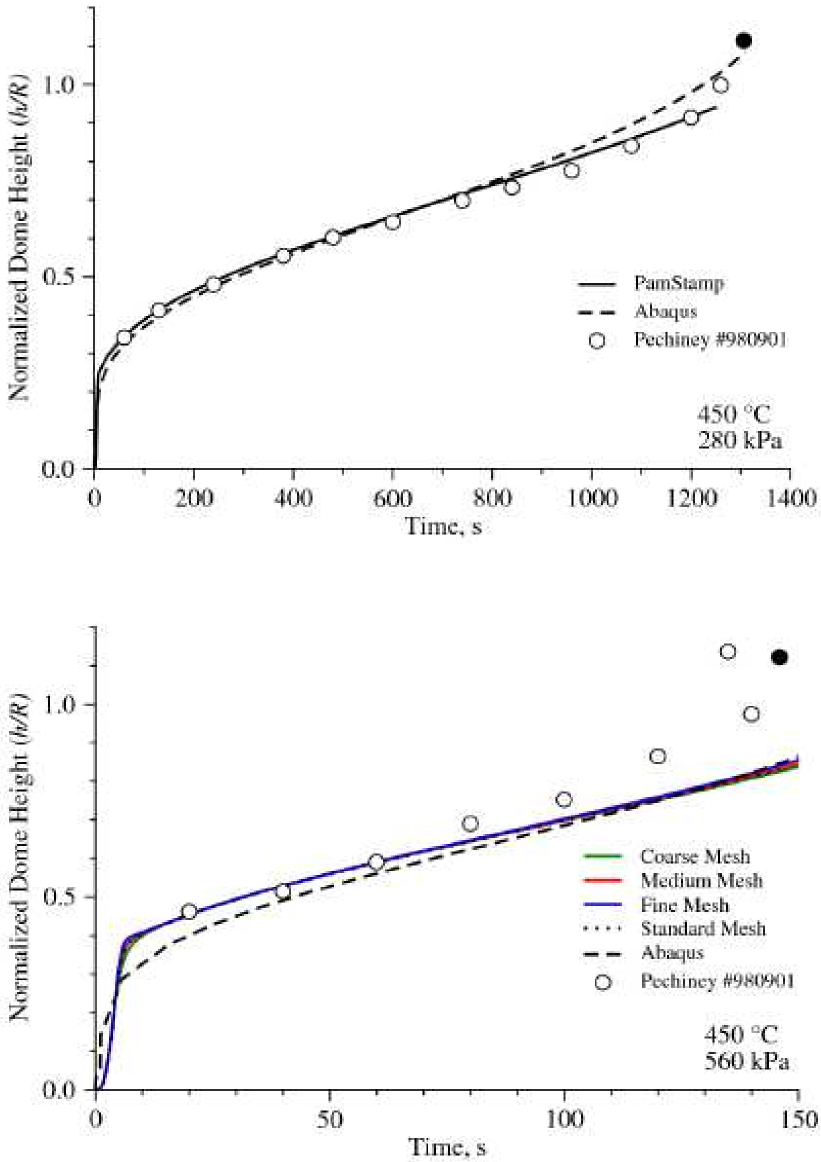


Figure 3.20: Simulating Elevated-Temperature Pneumatic Bulge Forming of AA5083, from [10]: Evolution of dome height normalized by die opening radius (h/R) from PAM-STAMP |2G™ and ABAQUS™ compared with experimental data collected at: (a) 1.2mm, 450°C, 280 kPa (40 psi); (b) 1.2 mm, 450°C, 500 kPa (81 psi) [10].

Chapter 4: Operational Instructions

The purpose of this chapter is to introduce the logical order of steps to achieve proper testing procedures. If steps are followed properly:

- Consistent results should be achieved;
- Risk of damage to the equipment should be reduced to a minimum.

This chapter will explain the reasoning behind the steps taken prior to the forming of the dome by gas-pressure blow-forming.

4.1. PRODUCTION OF SPECIMENS FOR TESTING

Chapter 2.5 described the force analysis for the forming of aluminum alloy AA5182 1.53 mm (0.060 in.) thick. If one is to test a thicker aluminum alloy or any other alloy of significantly different UTS properties, one must follow the procedure from Chapter 2.5 and solve for the different parameters needed to obtain a factor of safety.

Appendix B9 is the required drawing that any machine shop will require to reproduce the specimens.

4.2. BLEEDING THE AIR-LINES AND ADJUST REGULATED PRESSURE

See Chapter 4.6.1.

4.3. COOLING OF HEAT-EXCHANGERS

Heat-exchangers are required to be operational, before, during, and after the completion of the bulge testing at high temperatures. Figure 4.1 labels the valves (Figure 4.1(a)) and their open and closed positions (Figures 4.1(b) and (c)). Before the test starts complete the following:

-Open the return valve to the chilled water return;

-Then, open the valve from the chilled water supply.

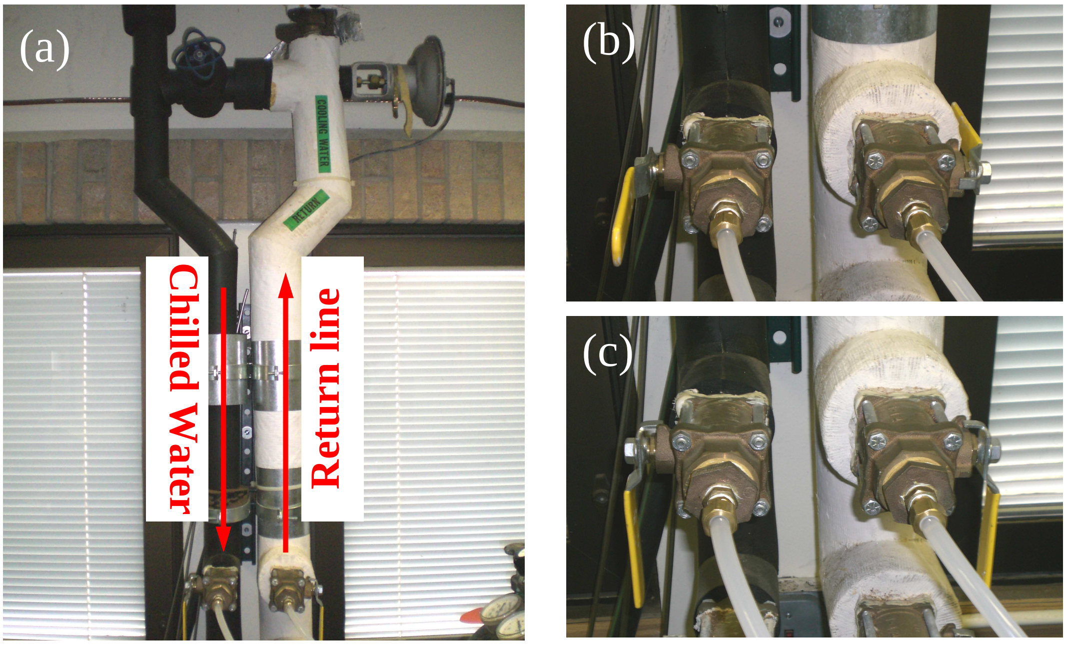


Figure 4.1: (a) chilled-water and return-line valves; (b) valves in the open-position; and (c) valves in the closed-position.

After the test is completed allow the system to cool down completely. DO NOT close the flow of cold water immediately after the experiment as been completed. Heat will travel through the loading-columns causing permanent damage to the electronic components, such as the load-cell of the servo-hydraulic unit and the micrometer.

After the system has reached room temperature complete the following:

-Close the valve from the chilled water supply;

-And, close the return to the chilled water return line;

4.4. Opening and Closing of Clamping Mechanism

The first step in the clamping process is to manually lower the ram of the servo-hydraulic unit down, preferably to create a gap of approximately 3 in. of clearance between the dies. It is important to keep in mind that the ram is the lower-end of the setup. Bringing the ram up or down (Figure 4.2) brings the bottom loading-column and the system to capture dome-peak displacement up or down the same distance. Since the loading-column main pipe and the measuring-rod were built from materials with similar mechanical properties and coefficients of expansion, expansion is expected to be nearly the same for both. Expansion in the direction of loading is nearly the same. Therefore, the relative location of the specimen to the dies and the measuring-rod should not change with the temperature changes.

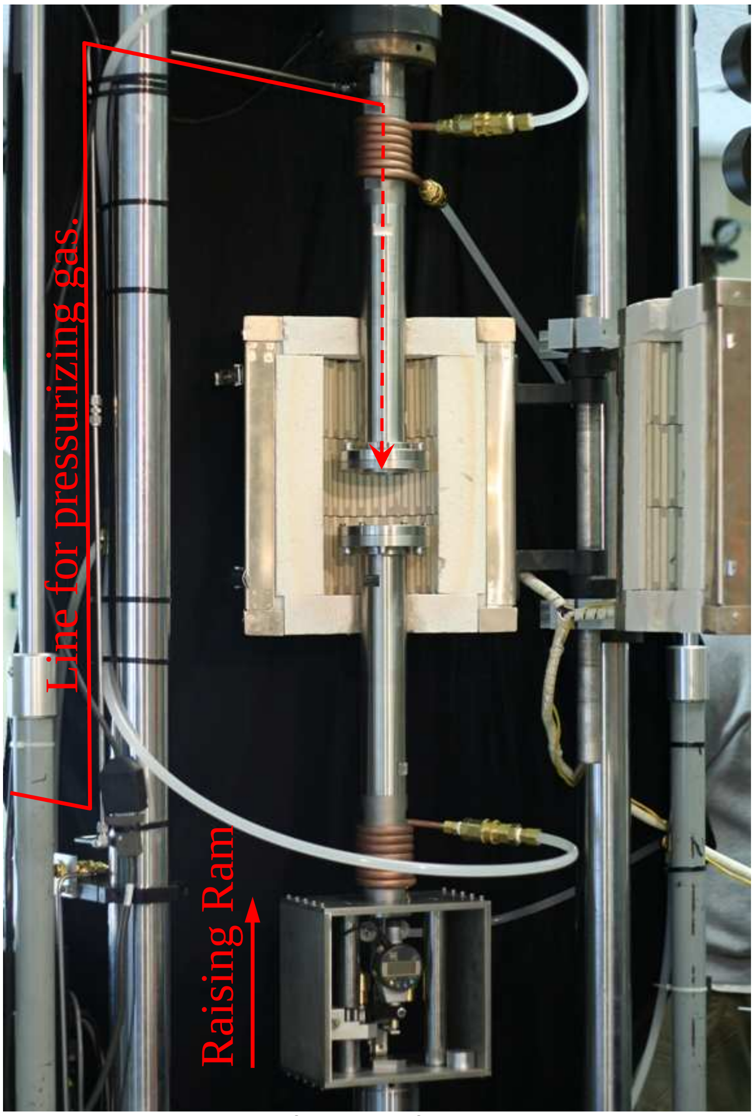


Figure 4.2: Basic features of the GPBF apparatus.
The path of gas-flow is shown.

The upper-end of the setup is attached to the load-cell. The amount of displacement of the upper-end is minimal. Damage to the load cell is possible if not paying close attention to die clearance.

Once the bottom die-ring has been lowered, it is a good time to spray anti-seize compound around the dies (both top and bottom, Figure 4.3) and on top of the measuring-rod tip (SAF-T-EZE® Nickel anti-seize aerosol, P/N SA-12N, is suggested). See Appendix D for MSDS. Only spray a thin layer of anti-seize, so it does not affect the testing results. Anti-seize particles are usually held together by viscous fluids that will evaporate at the temperatures at which the test occurs. After testing, it is a good practice to vacuum all the anti-seize particles so there is no build-up around the measuring-rod tip and around the dies.

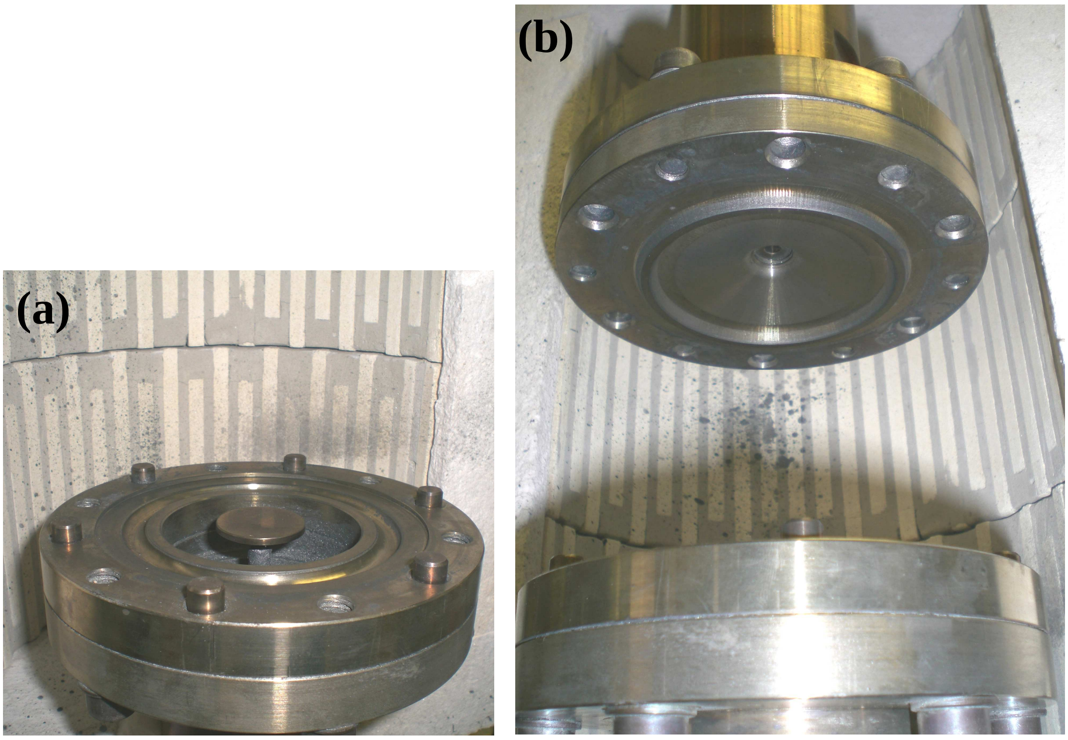


Figure 4.3: (a) bottom die-ring and tip of measuring-rod after been spayed with anti-seize compound; (b) top die-ring after sprayed with anti-seize compound.

At this point it is appropriate to load the specimen into the bottom die-ring (Figure 4.4).

Figure 4.4: Specimen loaded into the bottom die-ring.

Once the specimen is inside the bottom die-ring, move the ram up at a fairly low cross-head speed (1 in/min) until the distance between the flat faces of the die-rings are separated by 0.25 in. or slightly more (Figure 4.5). This is a good point to zero the z-axis of the computer interface that controls the ram of the servo-hydraulic unit. At this same cross-head speed (1 in/min), lower the ram down 3 in. and bring the ram up again to the zero reference point just obtained. This step allows manual rotation of the hydraulic piston to adjust alignment between the two mating dies. This is a good time to look at the alignment of the pins in the mating dies (Figure 4.6). There are two vertical marks that show the alignment of the dies. Verify with a straight edge that the alignment marks align within 1/64 in. Rotate the hydraulic piston manually to assure alignment.

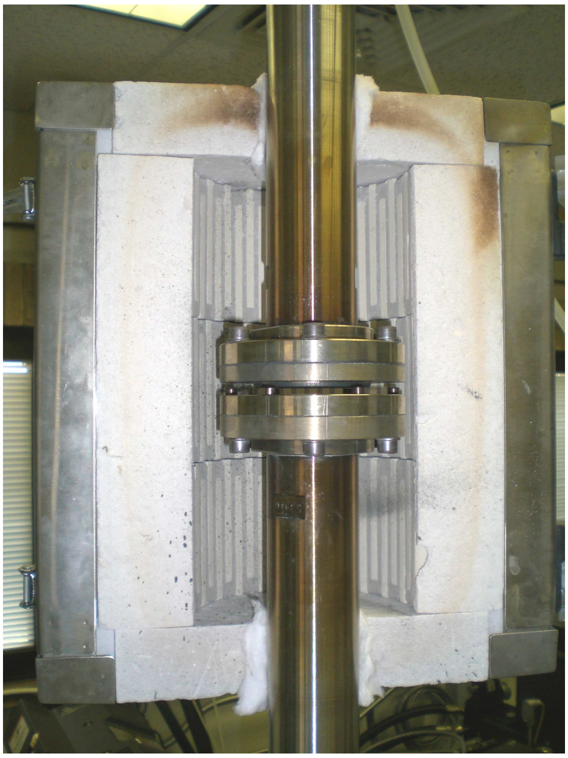


Figure 4.5: Clamping mechanism at the almost closed position.

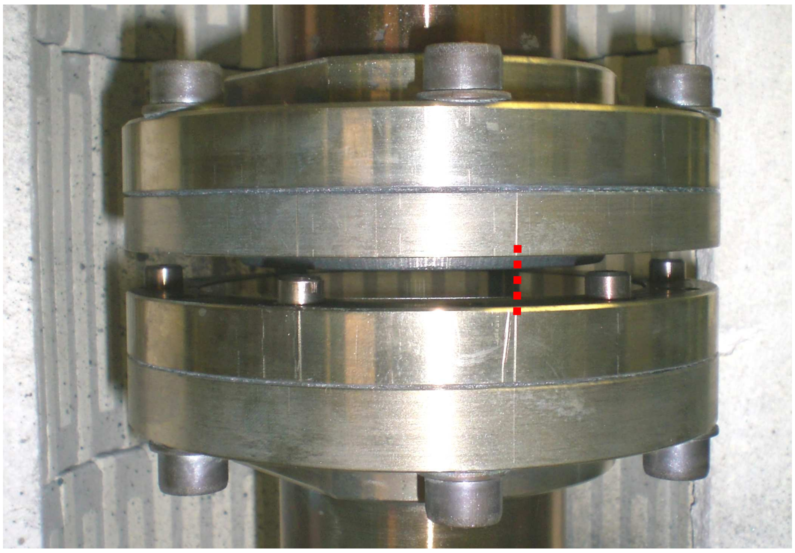


Figure 4.6: Alignment marks on the surface of the mating dies.

All the previous steps were performed with the furnace open and turned-off. It is important to confirm all alignments when the furnace is open and the die-rings are visible. Once the furnace is closed and operational, there is no easy way to check misalignment problems, and it is not until the setup is completed whether one can tell if something is wrong.

The final step in the setup routine for the clamping mechanism is to setup the closing during the heating cycle. See chapter 3.2 for details on the reasons why it is important to pay close attention of how the specimen is clamped between the die-rings during the heating cycle. It is a good idea to practice the loading routine with a blank of a soft material and the furnace open. The routine should bring the die bottom die-ring (where the specimen rests) up until the draw-bead of the top die-ring touches the blank; it will then close at a constant force rate until the required load is achieved; and it will then stop and maintain a constant load throughout the bulge forming test.

At this point the servo-hydraulic unit will start increasing the load at a rate of 2 lbf/s. Keep in mind that there is a big difference between running the loading routine when the system is at room temperature vs. running the system during the heating cycle. The expansion rate of the elements of the loading-column inside the furnace is faster than the load rate provided by the ram of the servo-hydraulic unit. Most likely it is the case that instead of the ram trying to close the gap between the dies to increase the load, it will lower the bottom die trying to adjust to the load rate of the routine as the fixture expands under heating. It could very well happen that the servo-hydraulic unit completely looses the target goal of maintaining a load rate of 2lbf/s and simply goes at the expansion rate of the loading-column. If this happens the operator must manually lower the ram to reduce the loading and prevent overloading.

Two advantages of progressively loading the dies to form the draw-bead are:

-The specimen will not sag, maintaining a very flat specimen to begin with;

-The tip of the measuring-rod can be in direct contact with the blank throughout the heating cycle, eliminating any questions about unexpected heating expansions.

4.5. DATA ACQUISITION

The data acquisition process is directly related to the smoothness of the micrometer's stem and the sliding-rail where the measuring-rod is mounted. It is important to properly lubricate both before each experiment. The calibration of the balancing weight requires that the ways of the sliding-rail be properly lubricated. It is appropriate to put a few drops of the ways-lube with a syringe on the ways of the sliding-rails and manually slide the sliding rail up and down 3 to 5 times (Figure 4.7). Way lube oil #68 (RAMCO® P/N 1011) was used to calibrate the sliding-rail. This is the way lube required to be used for the ways of the sliding rail. See Appendix D for MSDS.

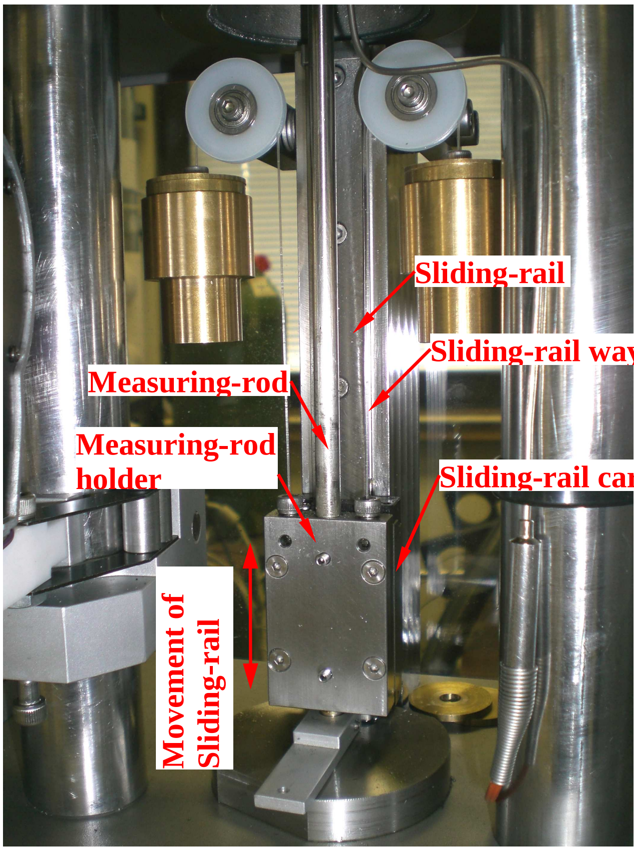


Figure 4.7: Sliding-rail and components.

As far as lubricating the micrometers stem, the best lubrication found after trying many different lubricants was to just thoroughly clean it with a fine paper cloth after applying a very light oil like WD-40. See Appendix D for MSDS. Oil alone creates a viscous effect on motion. The cleaner the stem walls the better is micrometer operation. It is good practice to lower the measuring-rod all the way to the bottom of the setup while keeping the micrometer up (Figure 4.8). With the measuring-rod at its lowest position, bring the micrometer's stem up and down a few times. If one lets the micrometer stem drop down by itself, it should slide down at a constant pace and rather fast. If the movement of the stem is choppy, the stem may require more cleaning. Bring the stem up and down a couple of times and try again. The total travel of the micrometer's stem is a little over 1.00 in. so, as one drops the micrometer's stem, it should travel 1.00 in.

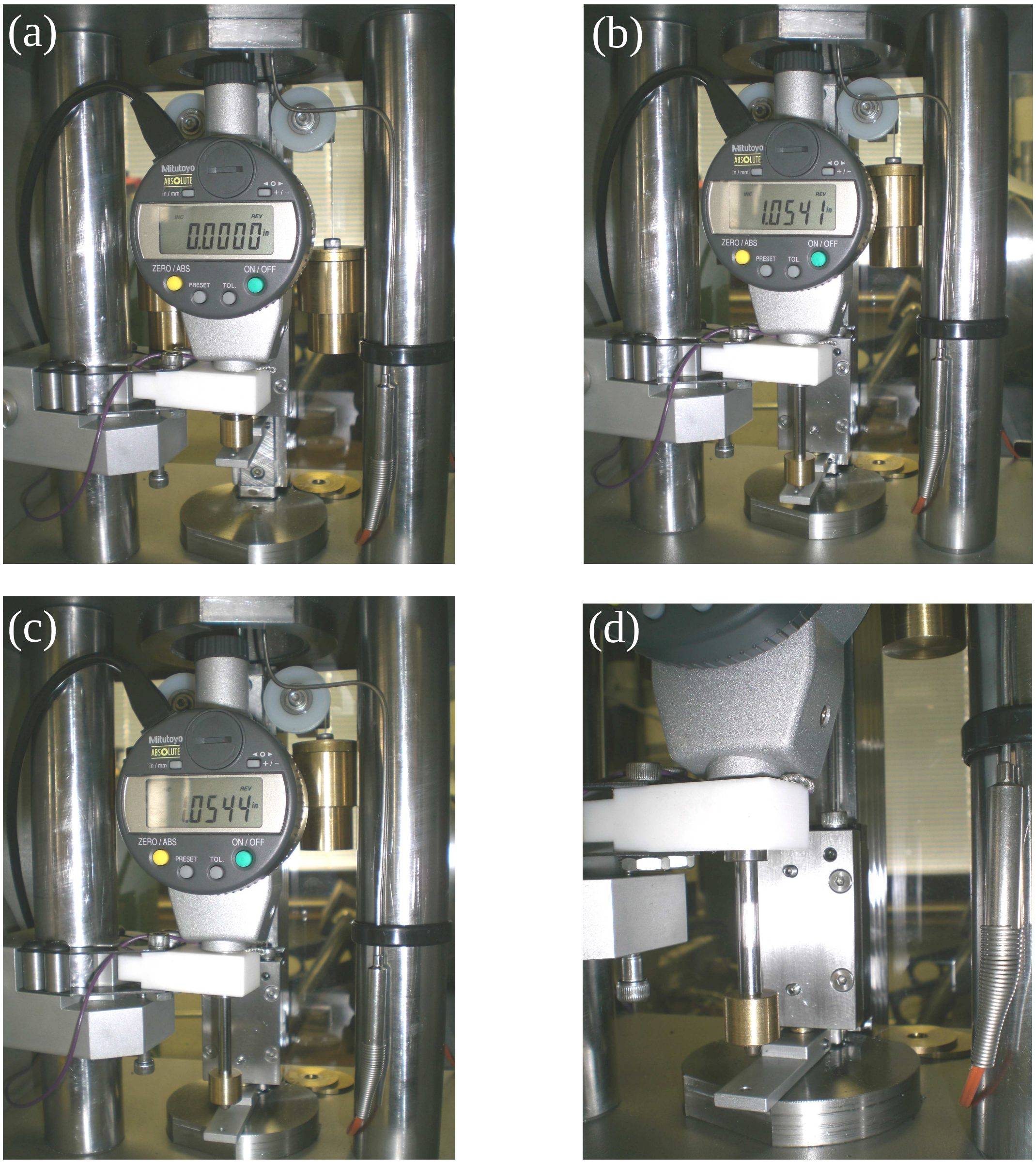


Figure 4.8: (a) measuring-rod rises until it touches the specimen. Micrometer is compressed to ~99% of its full displacement; (b) measuring-rod is lowered to ~99.5% the capacity of the micrometer; (c) measuring-rod is completely lowered. Reading of the micrometer is incorrect, since it is no longer touching the measuring-rod holder; and (d) micrometer's stem is completely down and ready to be cleaned.

After completing the lubrication process, the measuring-rod holder is to be raised until it touches the specimen. At this point the micrometer is to be turned on and zeroed

(Figure 4.8(a). This is the zero of the sample. If all previous procedures were followed properly, no displacement larger than 0.001 in. should be seen during the heating cycle. At this point the setup should have heated to the required temperature; the specimen should be fully clamped between the dies, and the measuring-rod tip contacting the specimen while the micrometer is reading 0.001 in. its worst case. At this point the computer interface is to be prepared for data acquisition. The computer interface captures recorded data from the micrometer. The computer's main job is to provide a time stamp to every data point captured from the micrometer by the computer interface. The time stamp is the basis for generating the plots of dome-peak height as a function of time.

The micrometer captures data from the stem displacement at around 4 to 5 readings per second. This step is limited by the speed of the micrometer. The computer should not be setup to capture more than 5 readings per second. If done incorrectly, the computer will re-read previous data-points and put a time stamp that is incorrect, resulting in false data. Tests can be as short as 10 minutes or as long as 3 hours, so it is a good idea to have the system to capture a very large amount of data-points and have the system manually stop once the test has been completed. It is appropriate to start capturing data at 1 or 2 seconds per datum prior to the opening of the gas valve for the actual bulge-forming.

4.6. Forming of the Specimen by Pressurized Gas

4.6.1. Bleeding the Air-lines and Adjust Regulated Pressure

Although this is the last step prior to the forming operation, there is one critical step that has to be done prior to any other step, bleeding the air lines while adjusting the pressure-regulator to the required pressure. The pressurized gas consists of a bottle of inert-gas (in this case Nitrogen) that has a regulator at its end (Figure 4.9(a)-(d)). The pressure-regulator connects to a 1-way valve (Figure 4.9(e)). The 1-way valve connects to the 2-way valve (Figure 4.10). This 2-way valve has 3 positions: The position to the left, which connects the gas from the reservoir to the line going into the die-ring; the center position, which blocks flow from the top die-ring to any other air-line; and the position to the right, which bleeds any previous built-up pressure in the lines of the top-die-ring to the room (Figure 4.10).

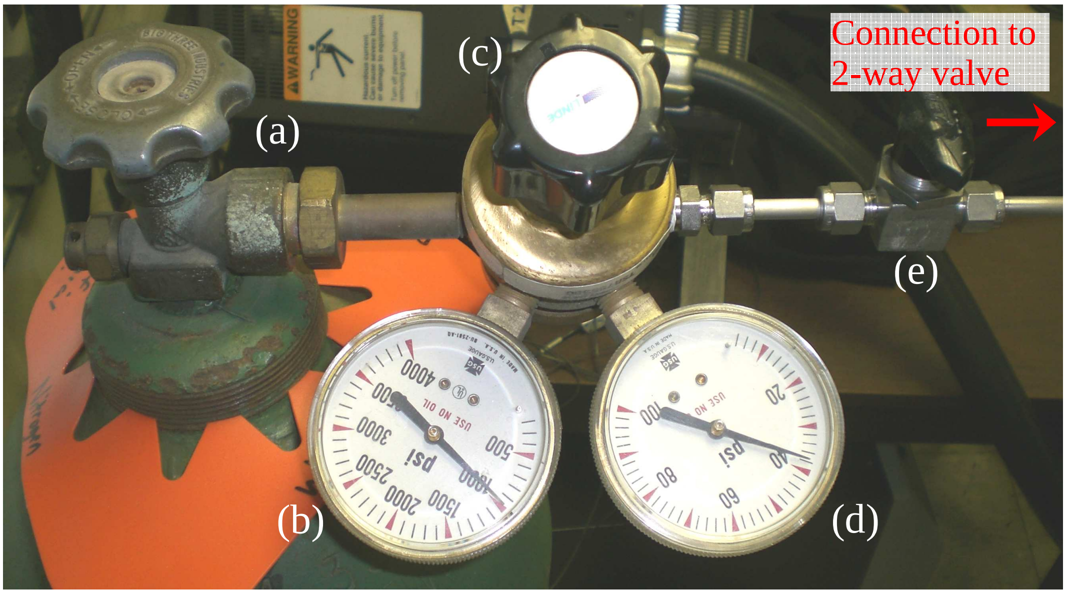


Figure 4.9: (a)Valve that controls the gas inside the bottle; (b) Pressure inside the bottle; (c) Pressure-regulator; (d) Pressure after the pressure-regulator; and (e) 1-way valve.

The first step in bleeding the lines is to set the 2-way valve to the left and the 1-way valve to the open position and then adjust the pressure-regulator to the pressure at which the experiment is required to run. After 1 or 2 seconds, close the 1-way valve and turn the 2-way valve to the right. By doing this, the pressure is set to the required value at which the experiment is going to run while the gas line from the 2-way valve to the die-ring has been bleed. The top die-ring is to be open to air during the heating cycle.

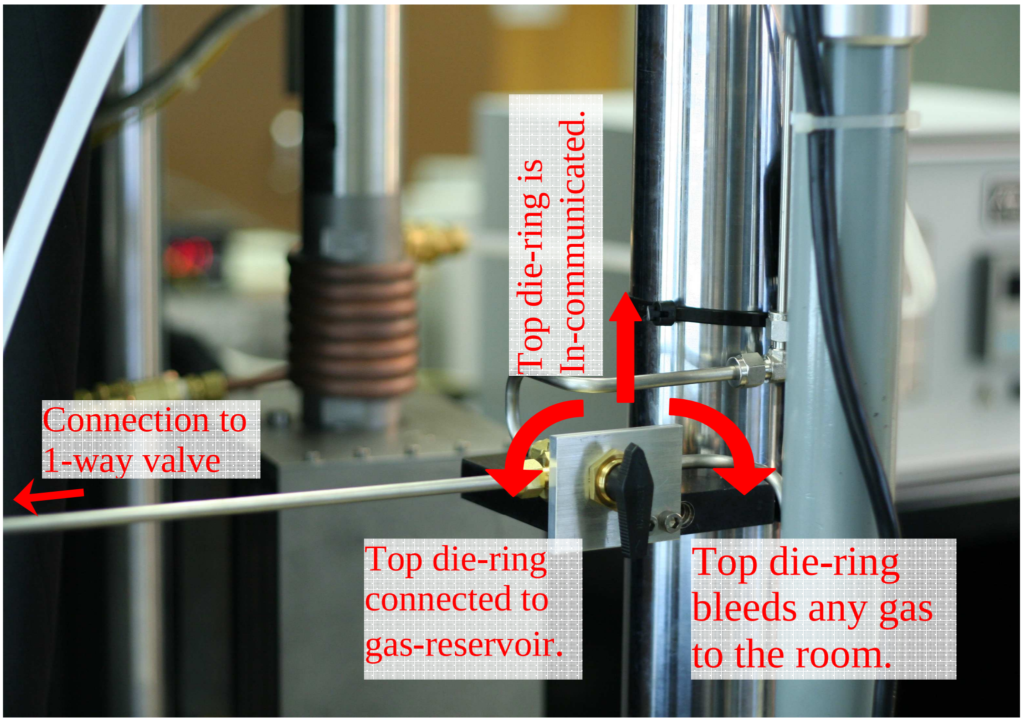


Figure 4.10: 2-way valve.

DO NOT follow any further instructions. Go back to Chapter 4.3.

4.6.2. Clamping of Specimen between Mating Dies

Follow the procedure developed in Chapter 3.2.

4.6.3. Forming of the Specimen

The final step in the process: All procedures have been followed from 4.2 to 4.6.2. It is time to form the specimen. The computer has already started capturing some data-points. At this point, turn the 2-way valve to the center point. Then, turn the 1-way valve open. Finally, turn the 2-way valve to the left as fast as one can. Pressurized gas at the pressure required by the experiment is entering the dies and forming the specimen.

Chapter 5: Conclusions and Future Work

5.1. Conclusions

The GPBF apparatus has proven to form a sheet of aluminum alloy AA5182 with a thickness of 1.5 mm into a dome with a height nearly equal to its radius under a constant gas pressure 40 psi at 450°C. The GPBF apparatus produced, for the first time to my knowledge, real-time dome peak displacement data as a function of time. Previous investigators have correlated dome peak displacement as a function of time at different stages during the forming of a dome, but no published data available has shown a continuous set of data points for an uninterrupted dome formed from a flat specimen until its rupture while the dome peak displacement has been captured.

The GPBF apparatus has proven to deliver the results expected. It is capable of handling the temperature and pressure requirements for QPF. The data captured from the testing of 2 specimens has proven to follow closely the pattern seen by the work of Hector et al. for the QPF of AA5083 at 40 and 80 psi at 450°C [10].

5.2. Future Work

The current system is capable of handling bulge forming pressures up to 100 psi, regulated. The pressure is regulated once at the beginning of each test and left set throughout the experiment. Adding a programmable pressure regulator with a wider pressure span could provide the following:

- Control the strain rate by changing the bulge forming pressures while the forming of the specimen is taking place;
- Perform bulge forming at higher pressures, allowing the testing of experiments at lower temperatures.

The micrometer chosen for the setup fulfills the requirements for the forming of alloys at temperature and pressure conditions where the h/r ratio is up to ~1. If temperature, pressure and alloy conditions allow the h/r to be significantly larger than 1 (~1.2 to ~1.5) the micrometer will not be able to capture all the displacement data. The micrometer will be out of travel. A 2 in. travel micrometer will provide the sufficient travel for the testing conditions where the specimen h/r ratio surpasses ~1.2.

Future designs can incorporate more advanced system for the capturing of surface displacement of the side of the sheet exposed to air. Computer-vision applications can be integrated to deliver stereo-vision profiles of the specimen as a function of time, providing a 3-dimensional profile of the specimen, compared to a single point dome height.

Appendix A

Swagelok® Stainless Steel Tubing and Fittings

Appendix A1: Stainless Steel Tubing

The following pages were taken from the Swagelok® catalog (www.swagelok.com)

Tubing Data

Contents

Tubing Selection

Proper selection, handling, and installation of tubing, when combined with proper selection of Swagelok® tube fittings, are essential to reliable tubing systems.

The following variables should be considered when ordering tubing for use with Swagelok tube fittings:

- Surface finish
- Material
- Hardness
- Wall thickness.

Tubing Surface Finish

Many ASTM specifications cover the above requirements, but they often are not very detailed on surface finish. For example, ASTM A450, a general tubing specification, reads:

> 11. Straightness and Finish
>
> 11.1 Finished tubes shall be reasonably straight and have smooth ends free of burrs. They shall have a workmanlike finish. Surface imperfections (Note) may be removed by grinding, provided that a smooth curved surface is maintained, and the wall thickness is not decreased to less than that permitted by this or the product specification. The outside diameter at the point of grinding may be reduced by the amount so removed.
>
> **Note:** An imperfection is any discontinuity or irregularity found in the tube.

Tubing Material

Our suggested ordering instructions for each type of tubing are shown under the respective tables.

Tubing Outside Diameter Hardness

The key to selecting proper tubing for use with metal Swagelok tube fittings is that the tubing must be softer than the fitting material. Swagelok tube fittings are designed to work properly with the tubing that is suggested in the ordering instructions.

Swagelok stainless steel tube fittings have been repeatedly tested successfully with tubing with hardness up to 200 HV and 90 HRB.

Tubing Wall Thickness

The accompanying tables show working pressure ratings of tubing in a wide range of wall thicknesses. Except as noted, allowable pressure ratings are calculated from *S* values as specified by ASME B31.3, Process Piping.

Swagelok tube fittings have been repeatedly tested in both the minimum and maximum wall thicknesses shown.

Swagelok tube fittings are not recommended for tube wall thicknesses outside the ranges shown in the accompanying tables for each size.

Tubing Handling

Good handling practices can greatly reduce scratches on tubing and protect the good surface finish that reliable tube manufacturers supply.

- Tubing should never be dragged out of a tubing rack or across a rough surface.
- Tube cutters or hacksaws should be sharp. Do not take deep cuts with each turn of the cutter or stroke of the saw.
- Tube ends should be deburred. This helps to ensure that the tubing will go all the way through the ferrules without damaging the ferrule sealing edge.

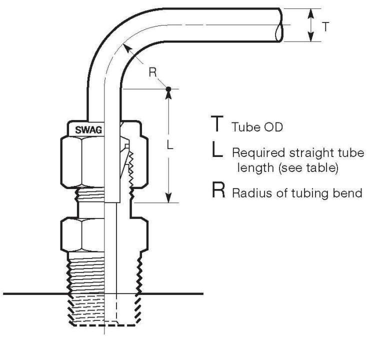
Gas Service

Gases (air, hydrogen, helium, nitrogen, etc.) have very small molecules that can escape through even the most minute leak path. Some surface defects on the tubing can provide such a leak path. As tube outside diameter (OD) increases, so does the likelihood of a scratch or other surface defect interfering with proper sealing.

The most successful connection for gas service will occur if all installation instructions are carefully followed and the heavier wall thicknesses of tubing on the accompanying tables are selected.

A heavy wall tube resists ferrule action more than a thin wall tube, allowing the ferrules to coin out minor surface imperfections. A thin wall tube offers less resistance to ferrule action during installation, reducing the chance of coining out surface defects, such as scratches. Within the applicable suggested allowable working pressure table, select a tube wall thickness whose working pressure is *outside* of the shaded areas.

Tubing Installation



Fractional, in.	
T Tube OD	L[1]
1/16	1/2
1/8	23/32
3/16	3/4
1/4	13/16
5/16	7/8
3/8	15/16
1/2	1 3/16
5/8	1 1/4
3/4	
7/8	1 5/16
1	1 1/2
1 1/4	2
1 1/2	2 13/32
2	3 1/4

[1] Required straight tube length.

Metric, mm	
T Tube OD	L[1]
3	19
6	21
8	23
10	25
12	31
14	32
15	
16	
18	
20	34
22	
25	40
28	46
30	50
32	54
38	63
50	80

Tubing properly selected and handled, when combined with the quality of Swagelok fittings, will give you leak-tight systems. Properly installed on such tubing, Swagelok fittings provide reliable service under a wide variety of fluid applications.

When installing fittings near tube bends, there must be a sufficient straight length of tubing to allow the tube to be bottomed in the Swagelok fitting (see tables).

For maximum assurance of reliable performance, use Swagelok tube fittings assembled in accordance with catalog instructions, and use properly selected and handled high-quality tubing—such as provided by Swagelok.

Hydraulic Swaging Unit

When installing carbon steel or stainless steel Swagelok tube fittings over 1 in. (25 mm), a Swagelok hydraulic swaging unit must be used. This unit provides sufficient pre-swaging of the ferrules onto the tubing for 1 1/4, 1 1/2 and 2 in. and 28, 30, 32, 38, and 50 mm Swagelok tube fittings. Ask your authorized Swagelok sales and service representative for a demonstration.

Suggested Allowable Pressure Tables

Figure and tables are for reference only. No implication is made that these values can be used for design work. Applicable codes and practices in industry should be considered. ASME Codes are the successor to and replacement of ASA Piping Codes.

- All pressures are calculated from equations in ASME B31.3, Process Piping. See factors for calculating working pressures in accordance with ASME B31.1, Power Piping.
- Calculations are based on maximum OD and minimum wall thickness, except as noted in individual tables.

  Example: 1/2 in. OD × 0.035 in. wall stainless steel tubing purchased to ASTM A269:

  OD Tolerance ± 0.005 in. / Wall Thickness ±10 %

  Calculations are based on 0.505 in. OD × 0.0315 in. wall tubing.
- No allowance is made for corrosion or erosion.

Suggested Allowable Working Pressure for *Stainless Steel Tubing*

Table 3—Fractional Stainless Steel Seamless Tubing

Allowable working pressures are calculated from an *S* value of 20 000 psi (137 800 kPa) for ASTM A269 tubing at –20 to 100°F (–28 to 37°C), as listed in ASME B31.3, except as noted. Multiply stainless steel rating by 0.94 for working pressure in accordance with ASME B31.1.

For Welded Tubing

For welded and drawn tubing, a derating factor must be applied for weld integrity:

- for double-welded tubing, multiply pressure rating by 0.85
- for single-welded tubing, multiply pressure rating by 0.80.

Tube OD in.	Tube Wall Thickness, in.																Swagelok Fitting Series
	0.010	0.012	0.014	0.016	0.020	0.028	0.035	0.049	0.065	0.083	0.095	0.109	0.120	0.134	0.156	0.188	
	Working Pressure, psig **Note:** For gas service, select a tube wall thickness outside of the shaded area. (See **Gas Service,** page 2.)																
1/16	5600	6800	8100	9400	12 000												100
1/8						8500	10 900										200
3/16						5400	7 000	10 200									300
1/4						4000	5 100	7 500	10 200[1]								400
5/16							4 000	5 800	8 000								500
3/8							3 300	4 800	6 500	7500[1][2]							600
1/2							2 600	3 700	5 100	6700							810
5/8								2 900	4 000	5200	6000						1010
3/4								2 400	3 300	4200	4900	5800					1210
7/8								2 000	2 800	3600	4200	4800					1410
1									2 400	3100	3600	4200	4700				1610
1 1/4										2400	2800	3300	3600	4100	4900		2000
1 1/2											2300	2700	3000	3400	4000	4900	2400
2												2000	2200	2500	2900	3600	3200

① For higher pressures, see the Swagelok *Medium-Pressure Fittings* catalog, MS-02-335, or the Swagelok *High-Pressure Fittings* catalog, MS-01-34.
② Rating based on repeated pressure testing of the Swagelok tube fitting with a 4:1 design factor based upon hydraulic fluid leakage.

Suggested Ordering Information

Fully annealed, high-quality (Type 304, 316, etc.) (seamless or welded and drawn) stainless steel hydraulic tubing, ASTM A269 or A213, or equivalent. Hardness 90 HRB (200 HV) or less. Tubing to be free of scratches, suitable for bending and flaring.

Note: Certain austenitic stainless tubing has an allowable ovality tolerance double the OD tolerance and may not fit into Swagelok precision tube fittings.

Table 4— Metric Stainless Steel Seamless Tubing

Allowable working pressures are based on equations from ASME B31.3 for EN ISO 1127 tubing (D4, T4 tolerance for 3 to 12 mm; D4, T3 tolerance 14 to 50 mm), using a stress value of 1370 bar (20 000 psi) and tensile strength of 5170 bar (75 000 psi), except as noted. Multiply stainless steel rating by 0.94 for working pressure in accordance with ASME B31.1.

For Welded Tubing

For welded and drawn tubing, a derating factor must be applied for weld integrity:

- for double-welded tubing, multiply pressure rating by 0.85
- for single-welded tubing, multiply pressure rating by 0.80.

Tube OD mm	Tube Wall Thickness, mm														Swagelok Fitting Series
	0.8	1.0	1.2	1.5	1.8	2.0	2.2	2.5	2.8	3.0	3.5	4.0	4.5	5.0	
	Working Pressure, bar **Note:** For gas service, select a tube wall thickness outside of the shaded area. (See **Gas Service**, page 2.)														
3	670														3M0
6	310	420	540	710											6M0
8		310	390	520											8M0
10		240	300	400	510	580									10M0
12		200	250	330	410	470									12M0
14		160	200	270	340	380	430								14M0
15		150	190	250	310	360	400								15M0
16			170	230	290	330	370	400[1]							16M0
18			150	200	260	290	320	370							18M0
20			140	180	230	260	290	330	380						20M0
22			140	160	200	230	260	300	340						22M0
25					180	200	230	260	290	320					25M0
28						180	200	230	260	280	330				28M0
30						170	180	210	240	260	310				30M0
32						160	170	200	220	240	290	330			32M0
38							140	160	190	200	240	270	310		38M0
50										150	180	210	240	270	50M0

① Rating based on repeated pressure testing of the Swagelok tube fitting with a 4:1 design factor based upon hydraulic fluid leakage.

Suggested Ordering Information

Fully annealed, high-quality (Type 304, 316, etc.) stainless steel tubing, EN ISO 1127 or equivalent. Hardness 200 HV (90 HRB) or less. Tubing to be free of scratches, suitable for bending or flaring.

Swagelok

Table 13—Fractional and Metric Alloy 825 Tubing

Allowable working pressures are based on equations from ASME BPV Section 2 Part D.

Tube OD in.	Tube Wall Thickness, in. 0.035	0.049	0.065	Swagelok Fitting Series
	Working Pressure, psig			
1/4	6400	9300	11 600[1]	400
3/8	4100	5900	8 200	600
1/2	3000	4300	5 900	800

[1] Based on repeated pressure testing of the Swagelok tube fitting with 4:1 design factor based upon hydraulic fluid leakage.

Tube OD mm	Tube Wall Thickness, mm 0.8	1.0	1.2	1.5	1.8	Swagelok Fitting Series
	Working Pressure, bar					
6	410	530	660			6M0
10		300	370	480		10M0
12		250	300	390	480	12M0

Suggested Ordering Information

Fully annealed seamless alloy 825 tubing, ASTM B163 or equivalent. Fully annealed welded alloy 825 tubing, ASTM B704, class 1 or equivalent. Hardness Rockwell 90 (201 HV) maximum on the 15T scale. Tubing to be free scratches, suitable for bending and flaring.

Table 14—Fractional and Metric Alloy 625 Tubing

Allowable working pressures are calculated from an *S* value of 26 700 psi (183 900 kPa) for ASTM B444 Grade 2 tubing at –20 to 100°F (–28 to 37°C), as listed in ASME BPV 2001 Section II, Part D, Table 1B; tubing outside diameter and wall thickness tolerances from ASTM B444 for small-diameter tube.

Tube OD in.	Tube Wall Thickness, in. 0.035	0.049	0.065	Swagelok Fitting Series
	Working Pressure, psig			
1/4	7300	10 700	14 600	400
3/8	4700	6 800	9 400	600
1/2	3500	5 000	6 800	800

Tube OD mm	Tube Wall Thickness, mm 0.8	1.0	1.2	1.5	1.8	Swagelok Fitting Series
	Working Pressure, bar					
6	470	610	750			6M0
10		350	430	550		10M0
12		290	350	450	550	12M0

Suggested Ordering Information

Fully annealed seamless alloy 625 tubing, ASTM B444, Grade 1 or equivalent. Hardness 25 HRC (266 HV) maximum. Tubing to be free scratches, suitable for bending and flaring.

Pressure Ratings at Elevated Temperatures

Table 15—Elevated Temperature Factors

Temperature °F	°C	Tubing Materials Al	Copper	Carbon Steel[1]	304 SS	316 SS	Alloy 400	Alloy 20[2]	Alloy C-276[2]	Alloy 600[2]	Ti	SAF 2507	Alloy 825	Alloy 625
200	93	1.00	0.80	0.95	1.00	1.00	0.87	1.00	1.00	1.00	0.86	0.90	1.00	0.93
400	204	0.40	0.50	0.87[1]	0.93	0.96	0.79	0.96	0.96	0.96	0.61	0.82	0.90	0.85
600	315				0.82	0.85	0.79	0.85	0.85	0.85	0.45	0.80	0.84	0.79
800	426				0.76	0.79	0.75	0.79	0.79	0.79			0.81	0.75
1000	537				0.69	0.76			0.76	0.35				0.73

[1] Based on 375°F (190°C) max.

[2] Based on the lower derating factor for stainless steel, in accordance with ASME B31.3.

To determine allowable working pressure at elevated temperatures, multiply allowable working pressures from Tables 1 through 14 by a factor shown in Table 15.

Example: Type 316 stainless steel 1/2 in. OD × 0.035 in. wall at 1000°F

1. The allowable working pressure at –20 to 100°F (–28 to 37°C) is 2600 psig (Table 3, page 4).
2. The elevated temperature factor for 1000°F (537°C) is 0.76 (Table 15, above):
   2600 psig × 0.76 = 1976 psig

The allowable working pressure for 316 SS 1/2 in. OD × 0.035 in. wall tubing at 1000°F (537°C) is 1976 psig.

Safe Product Selection
When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

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Appendix A2: Stainless Steel Fittings

The following pages were taken from the Swagelok® catalog (www.swagelok.com)

Materials

Materials Standards

Material	Bar Stock[1]	Forgings[2]
316 stainless steel	ASTM A276, ASME SA479, EN 1.4401	ASTM A182, ASME SA182, EN 1.4401
Alloy 20	ASTM B473	ASTM B462
Alloy 400/ R-405	ASTM B164, ASME SB164	ASTM B564, ASME SB564
Alloy 600	ASTM B166, ASME SB166	ASTM B564, ASME SB564
Alloy 625	ASTM B446[3]	ASTM B564, ASME SB564[4]
Alloy 825	ASTM B425	ASTM B564, ASME SB564
Alloy C-276	ASTM B574	ASTM B564
Aluminum	ASTM B211	ASTM B247
Brass	ASTM B16, ASTM B453	ASTM B283
Carbon steel	ASTM A108	—
Nylon	ASTM D4066	—
PFA[5]	—	ASTM D3307 Type I
PTFE	ASTM D1710	ASTM D3294
SAF 2507[6]	ASTM A479	ASTM A182
Titanium (grade 4)	ASTM B348	ASTM B381

[1] Straight fittings and tube adapters.
[2] Elbows, crosses, and tees.
[3] All straight fittings and tube adapters and 1/4 and 3/8 in.; 6 and 10 mm elbows, crosses, and tees.
[4] Elbows, crosses, and tees larger than 3/8 in. and 10 mm.
[5] See the Swagelok *PFA Tube Fittings and PFA Tubing* catalog, MS-01-05.
[6] See the Swagelok *Gaugeable SAF 2507 Super Duplex Tube Fittings* catalog, MS-01-174.

Additional Processing

Fitting bodies are processed for improved performance, as listed below. No additional processing is required for alloy 625, alloy 825, brass, nylon, 316 stainless steel, and PTFE materials.

Fitting Body Material	Process
Aluminum	Anodized, hydrocarbon film
Alloy 400/R-405, alloy 20, alloy C-276, alloy 600	Hydrocarbon film
Carbon steel (except weld bodies)	Zinc plating
Carbon steel (weld bodies)	Hydrocarbon film chemical conversion coating
Titanium	Anodized

- Over 1 in. and over 25 mm stainless steel fittings use stainless steel ferrules with PFA coating. Applications above 450°F (232°C) **require** silver-plated front ferrules and uncoated back ferrules. To order fittings with silver-plated front ferrules and uncoated back ferrules, add **-BM** to the fitting ordering number.

  Example: SS-2400-6-**BM**
- All carbon steel Swagelok tube fittings are supplied with 316 stainless steel back ferrules.

Alternative Fuels-Type Approval

Stainless steel Swagelok tube fittings used with 316 stainless steel and 316 Ti stainless steel alloy tubing as shown in the table have been tested to the requirements of ECE R110, EIHP Draft, and ECE R67.

Tube OD	Wall Thickness
3 to 16 mm	0.7 to 2.5 mm
1/8 to 5/8 in.	0.028 to 0.095 in.

Thread Specifications

Thread Type (End Connection)	Reference Specification
NPT	ASME B1.20.1, SAE AS71051
ISO/BSP (parallel) (Based on DIN 3852) (Swagelok PR, RP, and RS fittings)	ISO 228, JIS B0202
ISO/BSP (tapered) (Based on DIN 3852) (Swagelok RT fittings)	ISO 7, BS EN 10226-1, JIS B0203
ISO/BSP (gauge) (Based on EN 837-1 and 837-3) (Swagelok RG and RJ fittings)	ISO 228, JIS B0202
Unified (SAE) (Swagelok ST fittings)	ASME B1.1

Pipe Thread Sealants

A thread sealant should always be used when assembling tapered threads. SWAK® anaerobic pipe thread sealant and Swagelok PTFE tape are available. For more information, see the Swagelok *Tools and Accessories* catalog, MS-01-169.

O-Rings

O-seal fittings include a 70 durometer Buna N O-ring. Other straight-thread fittings with O-rings include a 90 durometer fluorocarbon FKM O-ring. Other O-ring materials are available upon request. O-rings are coated with a thin film of silicone-based lubricant. Removal of factory-applied lubricants may alter performance.

Cleaning and Packaging

Fitting components are cleaned to remove machine oil, grease, and loose particles. For more information, see Swagelok *Standard Cleaning and Packaging (SC-10),* MS-06-62.

Fittings are available individually bagged; add **CP** to the ordering number.

Example: SS-200-6**CP**

On request, fittings can be cleaned and packaged in accordance with Swagelok *Special Cleaning and Packaging (SC-11),* MS-06-63, with front ferrules silver plated and Krytox® 240 AC applied to the internal surface of the nut. To order, add **-BQ** to the ordering number.

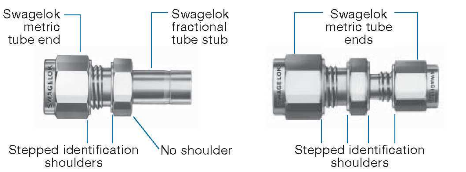
Example: SS-400-1-4-**BQ**

Oxygen Service Hazards

For more information about hazards and risks of oxygen-enriched systems, see the Swagelok *Oxygen System Safety* technical report, MS-06-13.

Metric Swagelok Tube Fittings

Metric tube fittings have a stepped shoulder on the body hex. Shaped fittings, such as elbows, crosses, and tees, are stamped MM for metric tubing and have no step on the forging.



Swagelok

Pressure Ratings

Swagelok Tube Fitting Pressure Ratings

Swagelok tube fitting ends are rated to the working pressure of tubing as listed in Swagelok *Tubing Data,* MS-01-107. Careful selection of high-quality tubing is important when installing safe, leak-tight systems.

Pipe End (NPT and ISO 7) Pressure Ratings Basis

Pressure ratings for fittings with both tube fitting and pipe thread ends are determined by the end connection with the lower pressure rating. The table lists pressure ratings for male and female **tapered pipe thread ends.** For female and male pipe threads to have the same pressure rating in the same nominal pipe size, the female thread would require a heavier wall, resulting in a fitting too large and bulky to be practical.

Allowable Stress

Stress values are based on ASME Code for Pressure Piping B31.3, Process Piping, at ambient temperature.

Material	Allowable Stress	
	psi	bar
316 SS	20 000	1378
Brass	10 000	689
Steel	20 000	1378

Pressure Ratings

Ratings are based on ASME Code for Pressure Piping B31.3, Process Piping, at ambient temperature.

NPT/ ISO Pipe Size	316 SS and Carbon Steel				Brass			
	Male		Female		Male		Female	
in.	psig	bar	psig	bar	psig	bar	psig	bar
1/16	11 000	760	6700	460	5500	380	3300	230
1/8	10 000	690	6500	440	5000	340	3200	220
1/4	8 000	550	6600	450	4000	270	3300	220
3/8	7 800	540	5300	360	3900	270	2600	180
1/2	7 700	530	4900	330	3800	260	2400	160
3/4	7 300	500	4600	320	3600	250	2300	160
1	5 300	370	4400	300	2600	180	2200	150
1 1/4	6 000	410	5000	350	3000	200	2500	170
1 1/2	5 000	340	4600	310	2500	170	2300	150
2	3 900	270	3900	270	1900	130	1900	130

- To determine pressure ratings in accordance with ASME B31.1, Power Piping:
  - stainless steel material—multiply by 0.94
  - carbon steel material—multiply by 0.85.

  Brass material ratings remain the same.
- To determine MPa, multiply bar by 0.10.

SAE/MS Fittings Pressure Ratings Basis

Pressure ratings are based on SAE J1926/3 at ambient temperature.

<table>
<tr><th rowspan="3">SAE/MS Thread Size</th><th rowspan="3">Designator</th><th colspan="4">316 SS and Carbon Steel</th></tr>
<tr><th colspan="2">Nonpositionable</th><th colspan="2">Positionable</th></tr>
<tr><th>psig</th><th>bar</th><th>psig</th><th>bar</th></tr>
<tr><td>5/16-24</td><td>2ST</td><td rowspan="5">4568</td><td rowspan="5">315</td><td rowspan="3">4568</td><td rowspan="3">315</td></tr>
<tr><td>7/16-20</td><td>4ST</td></tr>
<tr><td>1/2-20</td><td>5ST</td></tr>
<tr><td>9/16-18</td><td>6ST</td><td rowspan="2">3626</td><td rowspan="2">250</td></tr>
<tr><td>3/4-16</td><td>8ST</td></tr>
<tr><td>7/8-14</td><td>10ST</td><td rowspan="2">3626</td><td rowspan="2">250</td><td rowspan="2">2900</td><td rowspan="2">200</td></tr>
<tr><td>1 1/16-12</td><td>12ST</td></tr>
<tr><td>1 3/16-12</td><td>14ST</td><td rowspan="2">2900</td><td rowspan="2">200</td><td rowspan="2">2320</td><td rowspan="2">160</td></tr>
<tr><td>1 5/16-12</td><td>16ST</td></tr>
<tr><td>1 5/8-12</td><td>20ST</td><td rowspan="2">2320</td><td rowspan="2">160</td><td rowspan="2">1813</td><td rowspan="2">125</td></tr>
<tr><td>1 7/8-12</td><td>24ST</td></tr>
<tr><td>2 1/2-12</td><td>32ST</td><td>1813</td><td>125</td><td>1450</td><td>100</td></tr>
</table>

Some fittings with AN, O-seal, and SAE/MS ends may have lower ratings. For more information, contact your authorized Swagelok representative.

O-Seal Pressure Ratings

Stainless steel and carbon steel O-seal fittings up to 1 in. and 25 mm are rated to 3000 psig (206 bar).

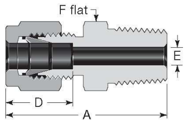
Positionable, ISO/BSP Parallel Thread (PR) Pressure Ratings

Pressure ratings are at ambient temperature.

<table>
<tr><th>ISO/BSP Male Pipe Size</th><th colspan="2">316 SS and Carbon Steel</th></tr>
<tr><th>in.</th><th>psig</th><th>bar</th></tr>
<tr><td>1/8</td><td rowspan="3">4568</td><td rowspan="3">315</td></tr>
<tr><td>1/4</td></tr>
<tr><td>3/8</td></tr>
<tr><td>1/2</td><td rowspan="3">2320</td><td rowspan="3">160</td></tr>
<tr><td>3/4</td></tr>
<tr><td>1</td></tr>
</table>

Straight Fittings

Male Connectors



NPT

Tube OD	NPT Size	Basic Ordering Number	Dimensions A	Dimensions D	Dimensions E①	Dimensions F
Dimensions, in.						
1/16	1/16 1/8 1/4	-100-1-1 -100-1-2 -100-1-4	0.94 1.03 1.22	0.34	0.05	5/16 7/16 9/16
1/8	1/16 1/8 1/4 3/8 1/2	-200-1-1 -200-1-2 -200-1-4 -200-1-6 -200-1-8	1.17 1.20 1.40 1.41 1.66	0.50	0.09	7/16 7/16 9/16 11/16 7/8
3/16	1/8 1/4	-300-1-2 -300-1-4	1.23 1.43	0.54	0.12	7/16 9/16
1/4	1/16 1/8 1/4 3/8 1/2 3/4	-400-1-1 -400-1-2 -400-1-4 -400-1-6 -400-1-8 -400-1-12	1.29 1.29 1.49 1.51 1.76 1.82	0.60	0.12 0.19 0.19 0.19 0.19 0.19	1/2 1/2 9/16 11/16 7/8 1 1/16
5/16	1/8 1/4 3/8	-500-1-2 -500-1-4 -500-1-6	1.34 1.52 1.54	0.64	0.19 0.25 0.25	9/16 9/16 11/16
3/8	1/8 1/4 3/8 1/2 3/4 1	-600-1-2 -600-1-4 -600-1-6 -600-1-8 -600-1-12 -600-1-16	1.39 1.57 1.57 1.82 1.88 2.14	0.66	0.19 0.28 0.28 0.28 0.28 0.28	5/8 5/8 11/16 7/8 1 1/16 1 3/8
1/2	1/8 1/4 3/8 1/2 3/4 1	-810-1-2 -810-1-4 -810-1-6 -810-1-8 -810-1-12 -810-1-16	1.53 1.71 1.71 1.93 1.99 2.25	0.90	0.19 0.28 0.38 0.41 0.41 0.41	13/16 13/16 13/16 7/8 1 1/16 1 3/8
5/8	1/4 3/8 1/2 3/4	-1010-1-4 -1010-1-6 -1010-1-8 -1010-1-12	1.74 1.74 1.93 1.99	0.96	0.28 0.38 0.47 0.50	15/16 15/16 15/16 1 1/16
3/4	3/8 1/2 3/4 1	-1210-1-6 -1210-1-8 -1210-1-12 -1210-1-16	1.80 1.99 1.99 2.25	0.96	0.41 0.47 0.62 0.62	1 1/16 1 1/16 1 1/16 1 3/8
7/8	1/2 3/4 1	-1410-1-8 -1410-1-12 -1410-1-16	1.99 1.99 2.25	1.02	0.47 0.62 0.72	1 3/16 1 3/16 1 3/8
1	1/2 3/4 1	-1610-1-8 -1610-1-12 -1610-1-16	2.26 2.26 2.45	1.23	0.47 0.62 0.88	1 3/8
1 1/8	1	-1810-1-16	2.45	1.23	0.88	1 5/8
1 1/4	1 1 1/4	-2000-1-16 -2000-1-20	3.04	1.62	0.88 1.09	1 3/4
1 1/2	1 1/2	-2400-1-24	3.50	1.97	1.34	2 1/8
2	2	-3200-1-32	4.47	2.66	1.81	2 3/4

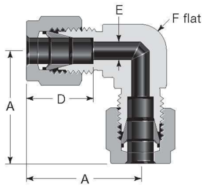
① The E dimension is the minimum nominal opening. These fittings may have a larger opening at the pipe/straight thread end.

Tube OD	NPT Size in.	Basic Ordering Number	Dimensions A	Dimensions D	Dimensions E①	Dimensions F
Dimensions, mm						
2	1/8	-2M0-1-2	30.5	12.9	1.7	12
3	1/8 1/4	-3M0-1-2 -3M0-1-4	30.5 35.6	12.9	2.4	12 14
4	1/8 1/4	-4M0-1-2 -4M0-1-4	31.2 36.3	13.7	2.4	12 14
6	1/8 1/4 3/8 1/2	-6M0-1-2 -6M0-1-4 -6M0-1-6 -6M0-1-8	32.8 37.9 38.4 44.7	15.3	4.8	14 14 18 22
8	1/8 1/4 3/8 1/2	-8M0-1-2 -8M0-1-4 -8M0-1-6 -8M0-1-8	34.2 38.7 39.3 45.6	16.2	4.8 6.4 6.4 6.4	15 15 18 22
10	1/8 1/4 3/8 1/2 3/4	-10M0-1-2 -10M0-1-4 -10M0-1-6 -10M0-1-8 -10M0-1-12	36.3 40.9 40.9 46.5 48.0	17.2	4.8 7.1 7.9 7.9 7.9	18 18 18 22 27
12	1/8 1/4 3/8 1/2 3/4	-12M0-1-2 -12M0-1-4 -12M0-1-6 -12M0-1-8 -12M0-1-12	38.8 43.4 43.4 49.0 50.5	22.8	4.8 7.1 9.5 9.5 9.5	22 22 22 22 27
14	1/4 3/8 1/2	-14M0-1-4 -14M0-1-6 -14M0-1-8	44.1 44.1 49.0	24.4	7.1 9.5 11.1	24
15	1/2	-15M0-1-8	49.0	24.4	11.9	24
16	3/8 1/2 3/4	-16M0-1-6 -16M0-1-8 -16M0-1-12	44.1 49.0 50.5	24.4	9.5 11.9 12.7	24 24 27
18	1/2 3/4	-18M0-1-8 -18M0-1-12	50.5	24.4	11.9 15.1	27
20	1/2 3/4	-20M0-1-8 -20M0-1-12	52.3	26.0	11.9 15.9	30
22	3/4 1	-22M0-1-12 -22M0-1-16	52.3 57.1	26.0	15.9 18.3	30 35
25	1/2 3/4 1	-25M0-1-8 -25M0-1-12 -25M0-1-16	57.5 57.5 62.3	31.3	11.9 15.9 21.8	35
28	1 1 1/4	-28M0-1-16 -28M0-1-20	72.4 73.1	36.6	21.8	41 46
30	1 1/4	-30M0-1-20	77.2	39.6	26.2	46
32	1 1/4	-32M0-1-20	79.6	42.0	28.6	46
38	1 1/2	-38M0-1-24	91.6	49.4	33.7	55

① The E dimension is the minimum nominal opening. These fittings may have a larger opening at the pipe/straight thread end.

90° Elbows

Unions



Tube ports are identical.

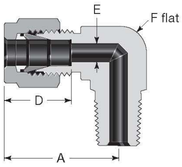
Tube OD	Basic Ordering Number	Dimensions			
		A	D	E	F
Dimensions, in.					
1/16	-100-9	0.70	0.34	0.05	3/8
1/8	-200-9	0.88	0.50	0.09	3/8
3/16	-300-9	1.00	0.54	0.12	1/2
1/4	-400-9	1.06	0.60	0.19	1/2
5/16	-500-9	1.13	0.64	0.25	9/16
3/8	-600-9	1.20	0.66	0.28	5/8
1/2	-810-9	1.42	0.90	0.41	13/16
5/8	-1010-9	1.50	0.96	0.50	15/16
3/4	-1210-9	1.57	0.96	0.62	1 1/16
7/8	-1410-9	1.76	1.02	0.72	1 3/8
1	-1610-9	1.93	1.23	0.88	1 3/8
1 1/8	-1810-9	2.17	1.23	0.97	1 11/16
1 1/4	-2000-9	2.67	1.62	1.09	1 11/16
1 1/2	-2400-9	3.10	1.97	1.34	2
2	-3200-9	4.22	2.66	1.81	2 3/4

Tube OD	Basic Ordering Number	Dimensions			
		A	D	E	F, in.
Dimensions, mm					
3	-3M0-9	22.3	12.9	2.4	3/8
4	-4M0-9	25.4	13.7	2.4	1/2
6	-6M0-9	27.0	15.3	4.8	1/2
8	-8M0-9	28.8	16.2	6.4	9/16
10	-10M0-9	31.5	17.2	7.9	11/16
12	-12M0-9	36.0	22.8	9.5	13/16
14	-14M0-9	38.0	24.4	11.1	15/16
15	-15M0-9	38.0	24.4	11.9	15/16
16	-16M0-9	38.0	24.4	12.7	15/16
18	-18M0-9	39.8	24.4	15.1	1 1/16
20	-20M0-9	44.6	26.0	15.9	1 3/8
22	-22M0-9	44.6	26.0	18.3	1 3/8
25	-25M0-9	49.1	31.3	21.8	1 3/8
28	-28M0-9	64.0	36.6	21.8	41 mm
30	-30M0-9	69.9	39.6	26.2	46 mm
32	-32M0-9	72.3	42.0	28.6	46 mm
38	-38M0-9	84.0	49.4	33.7	55 mm
50	-50M0-9	106	65.0	45.2	2 3/4

Swagelok

90° Elbows

Male



See page 8 for thread specifications.

NPT

Tube OD	NPT Size	Basic Ordering Number	Dimensions A	Dimensions D	Dimensions E ①	Dimensions F
			Dimensions, in.			
1/16	1/16 1/8	-100-2-1 -100-2-2	0.75	0.34	0.05	7/16
1/8	1/16 1/8 1/4	-200-2-1 -200-2-2 -200-2-4	0.93 0.93 0.97	0.50	0.09	7/16 7/16 1/2
3/16	1/8 1/4	-300-2-2 -300-2-4	1.00	0.54	0.12	1/2
1/4	1/16 1/8 1/4 3/8 1/2	-400-2-1 -400-2-2 -400-2-4 -400-2-6 -400-2-8	1.06 1.06 1.06 1.17 1.25	0.60	0.12 0.19 0.19 0.19 0.19	1/2 1/2 1/2 11/16 13/16
5/16	1/8 1/4 3/8	-500-2-2 -500-2-4 -500-2-6	1.13 1.13 1.20	0.64	0.19 0.25 0.25	9/16 9/16 11/16
3/8	1/8 1/4 3/8 1/2 3/4	-600-2-2 -600-2-4 -600-2-6 -600-2-8 -600-2-12	1.20 1.20 1.23 1.31 1.46	0.66	0.19 0.28 0.28 0.28 0.28	5/8 5/8 11/16 13/16 1 1/16
1/2	1/4 3/8 1/2 3/4	-810-2-4 -810-2-6 -810-2-8 -810-2-12	1.42 1.42 1.42 1.57	0.90	0.28 0.38 0.41 0.41	13/16 13/16 13/16 1 1/16
5/8	3/8 1/2 3/4	-1010-2-6 -1010-2-8 -1010-2-12	1.50 1.50 1.57	0.96	0.38 0.47 0.50	15/16 15/16 1 1/16
3/4	1/2 3/4	-1210-2-8 -1210-2-12	1.57	0.96	0.47 0.62	1 1/16
7/8	3/4	-1410-2-12	1.76	1.02	0.62	1 3/8
1	3/4 1	-1610-2-12 -1610-2-16	1.93	1.23	0.62 0.88	1 3/8
1 1/4	1 1/4	-2000-2-20	2.67	1.62	1.09	1 11/16
1 1/2	1 1/2	-2400-2-24	3.10	1.97	1.34	2
2	2	-3200-2-32	4.22	2.66	1.81	2 3/4

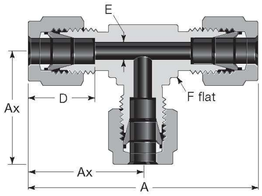
① The E dimension is the minimum nominal opening. These fittings may have a larger opening at the pipe/straight thread end.

Tube OD	NPT Size in.	Basic Ordering Number	Dimensions A	Dimensions D	Dimensions E ①	Dimensions F, in.
			Dimensions, mm			
3	1/8 1/4	-3M0-2-2 -3M0-2-4	23.6 24.6	12.9	2.4	7/16 1/2
4	1/8 1/4	-4M0-2-2 -4M0-2-4	25.4	13.7	2.4	1/2
6	1/8 1/4 3/8 1/2	-6M0-2-2 -6M0-2-4 -6M0-2-6 -6M0-2-8	27.0 27.0 29.8 31.8	15.3	4.8	1/2 1/2 11/16 13/16
8	1/8 1/4 3/8 1/2	-8M0-2-2 -8M0-2-4 -8M0-2-6 -8M0-2-8	28.8 28.8 30.6 32.6	16.2	4.8 6.4 6.4 6.4	9/16 9/16 11/16 13/16
10	1/8 1/4 3/8 1/2	-10M0-2-2 -10M0-2-4 -10M0-2-6 -10M0-2-8	31.5 31.5 31.5 33.5	17.2	4.8 7.1 7.9 7.9	11/16 11/16 11/16 13/16
12	1/4 3/8 1/2 3/4	-12M0-2-4 -12M0-2-6 -12M0-2-8 -12M0-2-12	36.0 36.0 36.0 39.8	22.8	7.1 9.5 9.5 9.5	13/16 13/16 13/16 1 1/16
15	1/2	-15M0-2-8	38.0	24.4	11.9	15/16
16	3/8 1/2 3/4	-16M0-2-6 -16M0-2-8 -16M0-2-12	38.0 38.0 39.8	24.4	9.5 11.9 12.7	15/16 15/16 1 1/16
18	1/2 3/4	-18M0-2-8 -18M0-2-12	39.8	24.4	11.9 15.1	1 1/16
20	1/2 3/4	-20M0-2-8 -20M0-2-12	44.6	26.0	11.9 15.9	1 3/8
22	3/4 1	-22M0-2-12 -22M0-2-16	44.6	26.0	15.9 18.3	1 3/8
25	3/4 1	-25M0-2-12 -25M0-2-16	49.1	31.3	15.9 21.8	1 3/8
30	1 1/4	-30M0-2-20	69.9	39.6	26.2	46 mm
32	1 1/4	-32M0-2-20	72.3	42.0	27.8	46 mm
38	1 1/2	-38M0-2-24	84.0	49.4	33.7	55 mm

① The E dimension is the minimum nominal opening. These fittings may have a larger opening at the pipe/straight thread end.

Tees

Unions

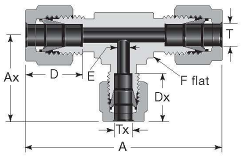


Union

Tube OD	Basic Ordering Number	Dimensions A	Ax	D	E	F
Dimensions, in.						
1/16	-100-3	1.40	0.70	0.34	0.05	3/8
1/8	-200-3	1.76	0.88	0.50	0.09	3/8
3/16	-300-3	1.92	0.96	0.54	0.12	7/16
1/4	-400-3	2.12	1.06	0.60	0.19	1/2
5/16	-500-3	2.34	1.17	0.64	0.25	5/8
3/8	-600-3	2.40	1.20	0.66	0.28	5/8
1/2	-810-3	2.84	1.42	0.90	0.41	13/16
5/8	-1010-3	3.06	1.53	0.96	0.50	1
3/4	-1210-3	3.14	1.57	0.96	0.62	1 1/16
7/8	-1410-3	3.52	1.76	1.02	0.72	1 3/8
1	-1610-3	3.86	1.93	1.23	0.88	1 3/8
1 1/8	-1810-3	4.34	2.17	1.23	0.97	1 11/16
1 1/4	-2000-3	5.34	2.67	1.62	1.09	1 11/16
1 1/2	-2400-3	6.20	3.10	1.97	1.34	2
2	-3200-3	8.44	4.22	2.66	1.81	2 3/4

Tube OD	Basic Ordering Number	Dimensions A	Ax	D	E	F, in.
Dimensions, mm						
2	-2M0-3	44.7	22.3	12.9	1.7	3/8
3	-3M0-3	44.7	22.3	12.9	2.4	3/8
4	-4M0-3	50.8	25.4	13.7	2.4	1/2
6	-6M0-3	53.9	27.0	15.3	4.8	1/2
8	-8M0-3	59.7	29.9	16.2	6.4	5/8
10	-10M0-3	63.0	31.5	17.2	7.9	11/16
12	-12M0-3	72.0	36.0	22.8	9.5	13/16
14	-14M0-3	77.6	38.8	24.4	11.1	1
15	-15M0-3	77.6	38.8	24.4	11.9	1
16	-16M0-3	77.6	38.8	24.4	12.7	1
18	-18M0-3	79.6	39.8	24.4	15.1	1 1/16
20	-20M0-3	89.3	44.6	26.0	15.9	1 3/8
22	-22M0-3	89.3	44.6	26.0	18.3	1 3/8
25	-25M0-3	98.3	49.1	31.3	21.8	1 3/8
28	-28M0-3	128	64.0	36.6	21.8	41 mm
30	-30M0-3	140	69.9	39.6	26.2	46 mm
32	-32M0-3	145	72.3	42.0	28.6	46 mm
38	-38M0-3	168	84.0	49.4	33.7	55 mm
50	-50M0-3	211	106	65.0	45.2	2 3/4

Reducing Union (Fractional)



Tube OD T	Tx	Basic Ordering Number	Dimensions A	Ax	D	Dx	E	F
Dimensions, in.								
3/8	1/4	-600-3-6-4	2.40	1.14	0.66	0.60	0.19	5/8
1/2	1/4 3/8	-810-3-8-4 -810-3-8-6	2.84	1.25 1.31	0.90	0.60 0.66	0.19 0.28	13/16
5/8	3/8	-1010-3-10-6	3.06	1.42	0.96	0.66	0.28	1
3/4	3/8 1/2	-1210-3-12-6 -1210-3-12-8	3.14	1.46 1.57	0.96	0.66 0.90	0.28 0.41	1 1/16
1	3/8 1/2 3/4	-1610-3-16-6 -1610-3-16-8 -1610-3-16-12	3.86	1.65 1.76 1.76	1.23	0.66 0.90 0.96	0.28 0.41 0.62	1 3/8
1 1/4	1	-2000-3-20-16	5.34	2.17	1.62	1.23	0.88	1 11/16
1 1/2	1	-2400-3-24-16	6.20	2.36	1.97	1.23	0.88	2
2	1	-3200-3-32-16	8.44	2.79	2.66	1.23	0.88	2 3/4

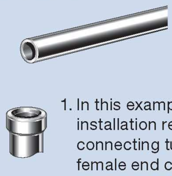
Tube Adapters

Solve Alignment Problems and Reduce Inventories

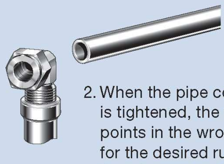
Swagelok tube adapters can help eliminate difficult alignment problems and reduce inventories. Swagelok tube adapters can be used with any Swagelok tube fittings in this catalog. So, stocking union elbows and union tees in various sizes and materials—along with commonly used Swagelok adapters—eliminates the need for stocking special elbows and tees.

Typical Alignment Problem

When installing pipe elbows or tees, it is often difficult to align the fitting with the desired run.



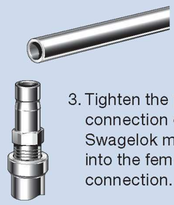
1. In this example, the installation requires connecting tubing to a female end connection.



2. When the pipe connection is tightened, the male elbow points in the wrong direction for the desired run. Loosening the pipe connection could mean leakage at the pipe thread.

Swagelok Solution

By using a Swagelok tube adapter in conjunction with a union elbow or tee, these difficulties can be avoided.



3. Tighten the pipe connection of a Swagelok male adapter into the female end connection.

4. Connect a Swagelok union elbow or tee to the adapter by tightening the Swagelok tube fitting with a wrench, while holding the elbow or tee in the desired direction. Insert the tubing into the other end of the Swagelok elbow or tee and install the fitting.

⚠ **Swagelok tube adapters are to be used ONLY in Swagelok tube fittings. Use in fittings made by other manufacturers may result in leakage or slippage.**

Additional Ordering Information

Swagelok tube fitting ordering numbers follow the sequence shown below.

A	-	B	C	D	-	E	-	F	G
SS	-	2	0	0	-	1	-	2	RT

A Material

A = Aluminum
B = Brass
C20 = Alloy 20
HC = Alloy C-276
INC = Alloy 600
M = Alloy 400/R-405
NY = Nylon
S = Carbon steel
SS = 316 stainless steel
T = PTFE
TI = Titanium
625 = Alloy 625
825 = Alloy 825

B Size (Tube OD)

Fractional, in.	**Metric,** mm
1 = 1/16	**2** = 2
2 = 1/8	**3** = 3
3 = 3/16	**4** = 4
4 = 1/4	**6** = 6
5 = 5/16	**8** = 8
6 = 3/8	**10** = 10
8 = 1/2	**12** = 12
10 = 5/8	**14** = 14
12 = 3/4	**15** = 15
14 = 7/8	**16** = 16
16 = 1	**18** = 18
18 = 1 1/8	**20** = 20
20 = 1 1/4	**22** = 22
24 = 1 1/2	**25** = 25
32 = 2	**28** = 28
	32 = 32
	38 = 38
	50 = 50

C Series

0 = Fractional 1/16 to 3/8 in. and 1 1/4 to 2 in.
1 = Fractional 1/2 to 1 1/8 in.
M = Millimeter tube size

To order a female Swagelok tube fitting, add **F**.
Example: SS-100**F**-1-1.

D Component

0 = Fitting
1 = Body

E Fitting Type

1 = Male connector
2 = 90° male elbow
3 = Tee, union
4 = Cross, union
5 = 45° male elbow
6 = Union
7 = Female connector
8 = Female elbow
9 = Elbow, union
11 = Bulkhead male connector
61 = Bulkhead union
71 = Bulkhead female connector
A = Adapter
C = Cap
P = Plug
PC = Port connector
R = Reducer
R1 = Bulkhead reducer
2R = Reducing elbow
TFT = Tee, female run
TMT = Tee, male run
TRT = Tee, ISO/BSP parallel male positionable run
TST = Tee, straight thread with O-ring male positionable run
TTF = Tee, female branch
TTM = Tee, male branch
TTR = Tee, ISO/BSP parallel male positionable branch
TTS = Tee, straight thread with O-ring male positionable branch

F Second End Connection Size

Add a size designator from the list at left for the second end connection *or* if the fitting is a reducing union.

G Second End Connection Type

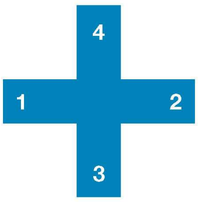
Add a second end connection type designator as needed.

AN = 37° male AN flare
ANF = 37° female AN flare
BT = Bored-through fitting
F = Female thread
KN = Knurled nut, nylon ferrules
KT = Knurled nut, PTFE ferrules
M = Metric tube end
OR = O-seal connection
PR = ISO/BSP positionable parallel pipe thread
RG = ISO/BSP parallel pipe thread (gauge)
RJ = ISO/BSP parallel pipe thread (Japanese gauge)
RP = ISO/BSP parallel pipe thread
RS = ISO/BSP parallel pipe thread
RT = ISO/BSP tapered pipe thread
ST = Straight thread with O-ring (for SAE/MS)
W = Male pipe weld/ tube socket weld

Tees and Crosses

Ordering numbers for tees and crosses indicate first the size of the run (**1** to **2**) and then the size of the branch (**3** for tees and **3** to **4** for crosses).

Example: SS-6M0-3-4TTF for a 316 SS female tee for 6 mm tube with 1/4 in. female NPT branch



Additional Sizes and Materials

Contact your authorized Swagelok representative for information about additional sizes and special alloys.

Additional Ordering Information

Swagelok tube adapter ordering numbers follow the sequence shown below.

A	-	B	-	C	-	D	-	E	F
SS	-	2	-	TA	-	1	-	4	RT

A Material

A = Aluminum
B = Brass
C20 = Alloy 20
HC = Alloy C-276
INC = Alloy 600
M = Alloy 400/R-405
NY = Nylon
S = Carbon steel
SS = 316 stainless steel
T = PTFE
TI = Titanium
625 = Alloy 625
825 = Alloy 825

B Size (Tube OD)

Fractional, in.	**Metric**, mm
1 = 1/16	**2** = 2
2 = 1/8	**3** = 3
3 = 3/16	**4** = 4
4 = 1/4	**6** = 6
5 = 5/16	**8** = 8
6 = 3/8	**10** = 10
8 = 1/2	**12** = 12
10 = 5/8	**14** = 14
12 = 3/4	**15** = 15
14 = 7/8	**16** = 16
16 = 1	**18** = 18
18 = 1 1/8	**20** = 20
20 = 1 1/4	**22** = 22
24 = 1 1/2	**25** = 25
32 = 2	**28** = 28
	32 = 32
	38 = 38
	50 = 50

C Component

TA = Fractional tube adapter
MTA = Metric tube adapter

D Adapter Type

1 = Male adapter
7 = Female adapter

E Second End Connection Size

Add a size designator from the list at left for the second end connection.

F Second End Connection Type

Add a second end connection type designator as needed.

AN = 37° male AN flare
ANF = 37° female AN flare
RG = ISO/BSP parallel pipe thread (gauge)
RJ = ISO/BSP parallel pipe thread (Japanese gauge)
RP = ISO/BSP parallel pipe thread
RS = ISO/BSP parallel pipe thread
RT = ISO/BSP tapered pipe thread
ST = Straight thread with O-ring (for SAE/MS)
W = Male pipe weld/ tube socket weld

Replacement Parts

To order, add a material designator from the **How to Order** table on page 10.

Nuts

Female

Tube OD	Basic Ordering Number	Dimensions G	Dimensions L
Dimensions, in.			
1/16	-102-1	5/16	0.31
1/8	-202-1	7/16	0.47
3/16	-302-1	1/2	0.47
1/4	-402-1	9/16	0.50
5/16	-502-1	5/8	0.53
3/8	-602-1	11/16	0.56
1/2	-812-1	7/8	0.69
5/8	-1012-1	1	0.69
3/4	-1212-1	1 1/8	0.69
7/8	-1412-1	1 1/4	0.69
1	-1612-1	1 1/2	0.81
1 1/4	-2002-1	1 7/8	1.25
1 1/2	-2402-1	2 1/4	1.50
2	-3202-1	3	2.06

Tube OD	Basic Ordering Number	Dimensions G	Dimensions L
Dimensions, mm			
2	-2M2-1	12	11.9
3	-3M2-1	12	11.9
4	-4M2-1	12	11.9
6	-6M2-1	14	12.7
8	-8M2-1	16	13.5
10	-10M2-1	19	15.1
12	-12M2-1	22	17.4
14	-14M2-1	25	17.4
15	-15M2-1	25	17.4
16	-16M2-1	25	17.4
18	-18M2-1	30	17.4
20	-20M2-1	32	17.4
22	-22M2-1	32	17.4
25	-25M2-1	38	20.6
28	-28M2-1	46	30.6
30	-30M2-1	50	32.7
32	-32M2-1	50	34.4
38	-38M2-1	50	40.6
50	-50M2-1	3 in.	52.3

Knurled Female

The Swagelok knurled nut tube fitting provides a leak-tight seal without the use of inserts on most wall thicknesses of polyethylene tubing. Inserts may be required for larger sizes.

To set the ferrules on the tubing, initial connections must be made with a wrench, tightening the nut one and one-quarter turns from finger-tight (three-quarter turn for 1/16, 1/8 and 3/16 in.; 2, 3, and 4 mm fittings). Leak-tight connections may be reassembled with finger-tight assembly.

To order a knurled nut, add **K** to the female nut basic ordering number.

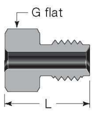
Example: B-402-1**K**

To order a knurled nut on an assembled fitting with nylon ferrules, add **KN** to the fitting ordering number.

Example: SS-400-1-2**KN**

To order a knurled nut on an assembled fitting with PTFE ferrules, add **KT** to the fitting ordering number.

Example: SS-400-1-2**KT**



For use in female Swagelok end connections.

Male

Tube OD	Basic Ordering Number	Dimensions G	Dimensions L
Dimensions, in.			
1/16	-1F2-1GC	1/4	0.38
1/8	-2F2-1GC	3/8	0.53
1/4	-4F2-1	1/2	0.62
1/2	-8F2-1	15/16	0.87

Tube OD	Basic Ordering Number	Dimensions G	Dimensions L
Dimensions, mm			
10	-10MF2-1	22	22.1
12	-12MF2-1	24	22.1

Replacement Parts

To order, add a material designator from the **How to Order** table on page 10.

Ferrules

Front

Tube OD	Basic Ordering Number
Dimensions, in.	
1/16	-103-1
1/8	-203-1
3/16	-303-1
1/4	-403-1
5/16	-503-1
3/8	-603-1
1/2	-813-1
5/8	-1013-1
3/4	-1213-1
7/8	-1413-1
1	-1613-1
1 1/4	-2003-1①
1 1/2	-2403-1①
2	-3203-1①

① Over 1 in. and over 25 mm stainless steel front ferrules are PFA coated. To order silver-plated front ferrules, add **-BL** to the basic ordering number.
Example: SS-2003-1-**BL**

Tube OD	Basic Ordering Number
Dimensions, mm	
2	-2M3-1
3	-3M3-1
4	-4M3-1
6	-6M3-1
8	-8M3-1
10	-10M3-1
12	-12M3-1
14	-14M3-1
15	-15M3-1
16	-16M3-1
18	-18M3-1
20	-20M3-1
22	-22M3-1
25	-25M3-1
28	-28M3-1①
30	-30M3-1①
32	-32M3-1①
38	-38M3-1①
50	-50M3-1①

Back

Tube OD	Basic Ordering Number
Dimensions, in.	
1/16	-104-1
1/8	-204-1
3/16	-304-1
1/4	-404-1
5/16	-504-1
3/8	-604-1
1/2	-814-1
5/8	-1014-1
3/4	-1214-1
7/8	-1414-1
1	-1614-1
1 1/4	-2004-1①
1 1/2	-2404-1①
2	-3204-1①

① Over 1 in. and over 25 mm stainless steel back ferrules are PFA coated. To order back ferrules without PFA coating, add **-WC** to the basic ordering number.
Example: SS-2004-1-**WC**

Tube OD	Basic Ordering Number
Dimensions, mm	
2	-2M4-1
3	-3M4-1
4	-4M4-1
6	-6M4-1
8	-8M4-1
10	-10M4-1
12	-12M4-1
14	-14M4-1
15	-15M4-1
16	-16M4-1
18	-18M4-1
20	-20M4-1
22	-22M4-1
25	-25M4-1
28	-28M4-1①
30	-30M4-1①
32	-32M4-1①
38	-38M4-1①
50	-50M4-1①

Replacement Parts

Nut-Ferrule Set and Ferrule Set

Use of Nuts and Ferrules

Using Swagelok nuts and ferrules on tube fittings or valves with tube end connections requires critical interaction of precision parts.

Swagelok nuts and ferrules are sold as replacement parts for use with only Swagelok bodies, fittings, valves, and hose products.

Sets are shown with arbors. One arbor holds five nut-ferrule sets or ten ferrule sets.

Nut-Ferrule Set

The nut-ferrule set contains one nut, one back ferrule, and one front ferrule.

To order, add a material designator to the basic ordering number. Please order nut-ferrule sets in multiples of five.

Example: **SS**-400-NFSET

Material	Designator
Brass	B
Carbon steel	S
316 stainless steel	SS

Tube OD	Basic Ordering Number
Dimensions, in.	
1/4	-400-NFSET
3/8	-600-NFSET
1/2	-810-NFSET
Dimensions, mm	
6	-6M0-NFSET
8	-8M0-NFSET
10	-10M0-NFSET
12	-12M0-NFSET

Ferrule Set

The ferrule set contains one front ferrule and one back ferrule.

To order, add a material designator to the basic ordering number. Please order ferrule sets in multiples of ten.

Example: **SS**-100-SET

Material	Designator
Alloy 400/R-405	M
Aluminum	A
Brass	B
Carbon steel	S
Nylon	NY
PTFE	T
316 stainless steel	SS

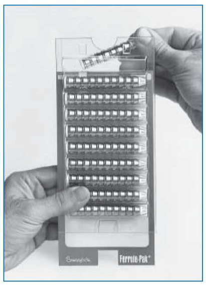
Tube OD	Basic Ordering Number
Dimensions, in.	
1/16	-100-SET
1/8	-200-SET
3/16	-300-SET
1/4	-400-SET
5/16	-500-SET
3/8	-600-SET
1/2	-810-SET
Dimensions, mm	
6	-6M0-SET
8	-8M0-SET
10	-10M0-SET
12	-12M0-SET

Nut-Ferrule Package and Ferrule-Pak Package

To order the nut-ferrule package (50 nut-ferrule sets) or ferrule-pak package (100 front and back sets), contact your authorized Swagelok sales and service representative.

Nut-Ferrule Package

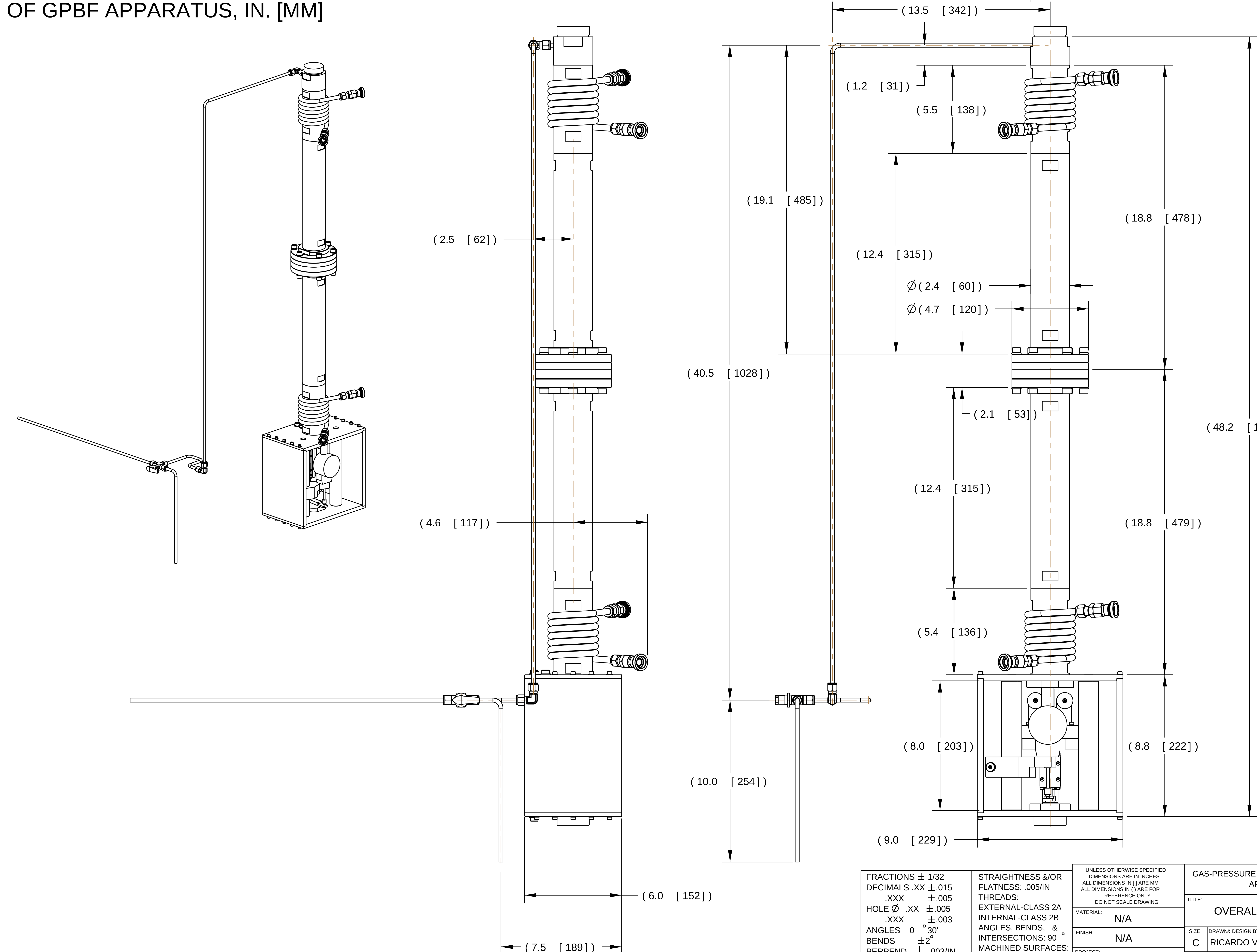
Ferrule-Pak Package



Appendix B

Assembly Drawings

APPENDIX B1: OVERALL DIMENSIONS OF GPBF APPARATUS, IN. [MM]



FRACTIONS ± 1/32
DECIMALS .XX ±.015
.XXX ±.005
HOLE ∅ .XX ±.005
.XXX ±.003
ANGLES 0 ° 30'
BENDS ±2°
PERPEND. ⊥ .003/IN
CONCEN. ◎ .003/IN

STRAIGHTNESS &/OR FLATNESS: .005/IN
THREADS:
EXTERNAL-CLASS 2A
INTERNAL-CLASS 2B
ANGLES, BENDS, & INTERSECTIONS: 90 °
MACHINED SURFACES: 63/ OR BETTER

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ALL DIMENSIONS IN [ ] ARE MM
ALL DIMENSIONS IN ( ) ARE FOR REFERENCE ONLY
DO NOT SCALE DRAWING

MATERIAL: N/A
FINISH: N/A
PROJECT: GAS PRESSURE FORMING

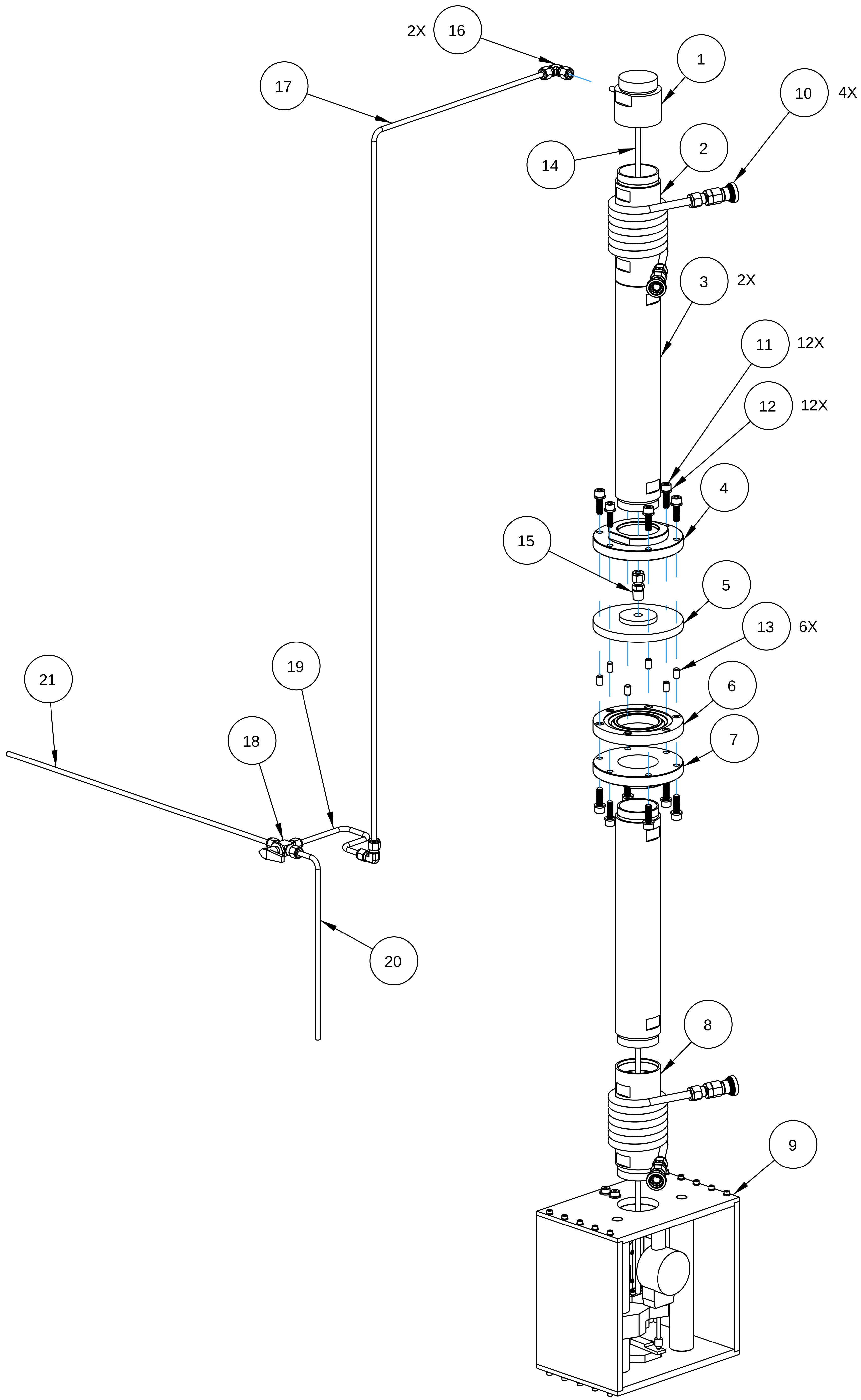
GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS

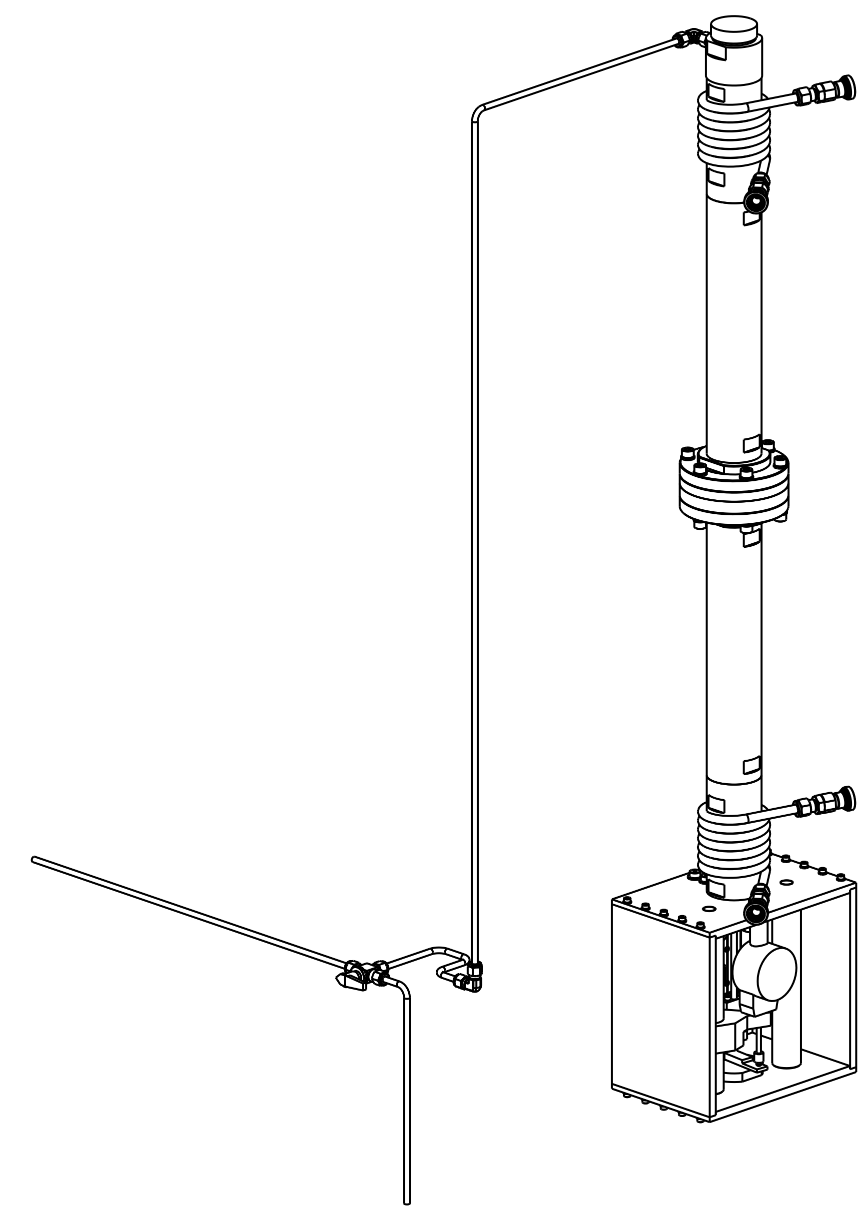
TITLE: OVERALL DIMENSIONS

SIZE	DRAWN& DESIGN BY:	REV
C	RICARDO VANEGAS MOLLER	0

SCALE: 1:4 DWG NO. SHEET: 1 OF 1

APPENDIX B2: BILL OF MATERIALS (BOM) FOR MAIN ASSEMBLY





Item No.	Description	Manufacturer	P/N	Material	QTY
1	Load-Cell Thread Adapter		N/A	SS304	1
2	Top Heat-Exchanger		N/A	SS304	1
3	Loading-Column Pipe		N/A	SS316	2
4	Die-Holder		N/A	INC600	1
5	Top Die-Ring		N/A	INC600	1
6	Bottom Die-Ring		N/A	INC600	1
7	Die-Holder		N/A	INC600	1
8	Bottom Heat-Exchanger		N/A	SS304	1
9	BOTTOM SUBASSEMBLY		N/A	N/A	1
10	NPT Pipe x Quick-Disconnect	McMaster	5316K13	BRASS	4
11	Cap Screw M8 Thread, 25mm Length, 1.25mm Pitch	McMaster	92290A432	SS316	12
12	Flat Washer M8, 8.4mm ID, 16mm OD, 1.40-1.8mm Thk	McMaster	90965A190	SS316	12
13	Alignment Pins		N/A	SS304	6
14	Top Loading-Column Pipe. 1/4 in. OD 0.035 in. wall	McMaster	89785K125	SS316	1
15	Male Connector 1/4 in. OD, 1/4 NPT	Swagelok	1/4-400-1-4	SS316	1
16	Union 90 Degree Elbow	Swagelok	1/4-400-9	SS316	2
17	316 stainless steel 1/4 in. OD 0.035 in. wall	McMaster	89785K51	SS316	1
18	Ball Valve with Yor-Lok, 3-Way, 1/4" Tube OD	McMaster	4566K98	BRASS	1
19	316 stainless steel 1/4 in. OD 0.035 in. wall	McMaster	89785K225	SS316	1
20	316 stainless steel 1/4 in. OD 0.035 in. wall	McMaster	89785K225	SS316	1
21	316 stainless steel 1/4 in. OD 0.035 in. wall	McMaster	89785K225	SS316	1

FRACTIONS ± 1/32
DECIMALS .XX ±.015
.XXX ±.005
HOLE Ø .XX ±.005
.XXX ±.003
ANGLES 0° 30'
BENDS ±2°
PERPEND. ⊥ .003/IN
CONCEN. ◎ .003/IN

STRAIGHTNESS &/OR FLATNESS: .005/IN
THREADS:
EXTERNAL-CLASS 2A
INTERNAL-CLASS 2B
ANGLES, BENDS, & INTERSECTIONS: 90°
MACHINED SURFACES: 63 OR BETTER

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ALL DIMENSIONS IN [ ] ARE MM
ALL DIMENSIONS IN ( ) ARE FOR REFERENCE ONLY
DO NOT SCALE DRAWING

MATERIAL: N/A
FINISH: N/A
PROJECT: GAS PRESSURE FORMING

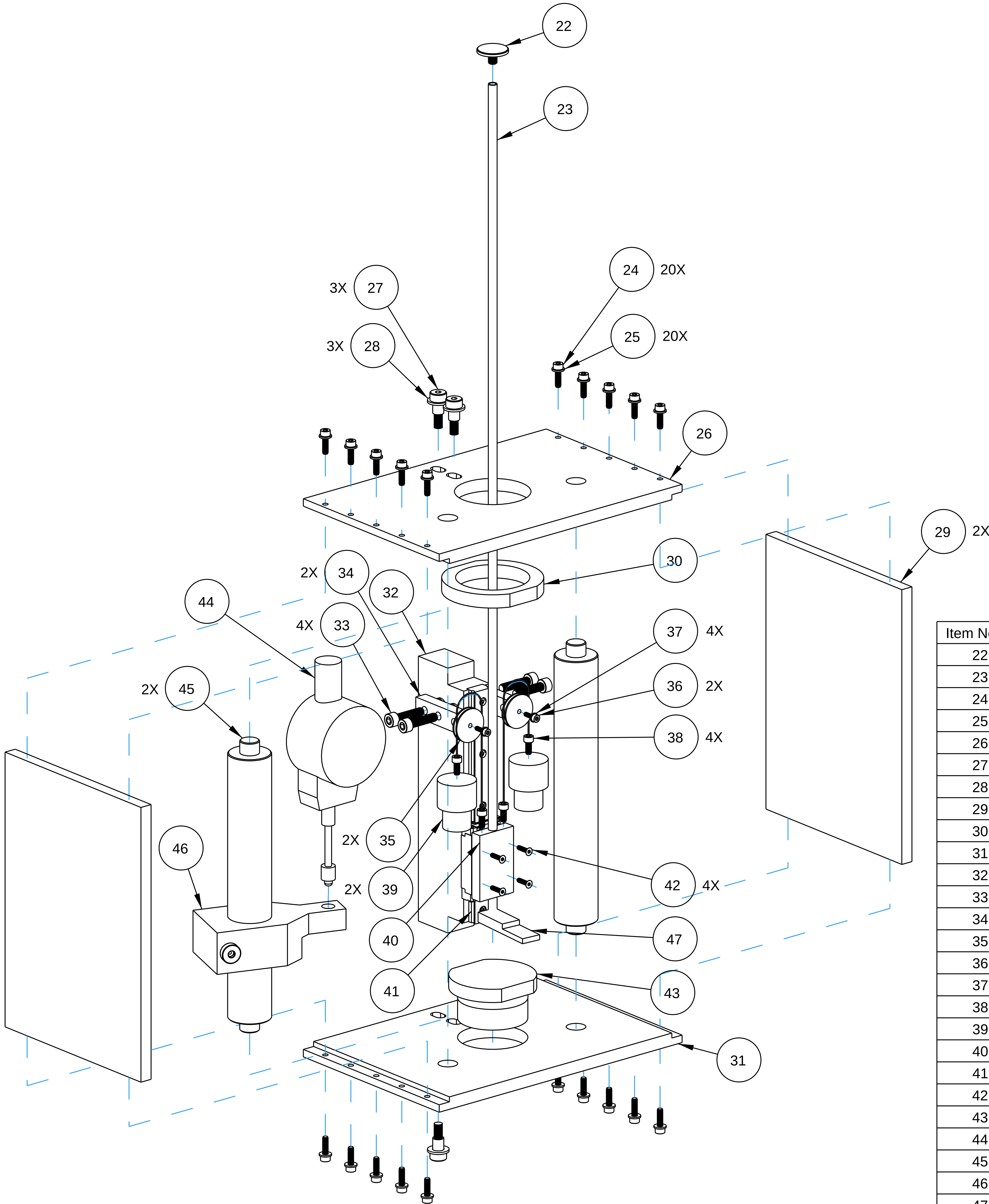
GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS

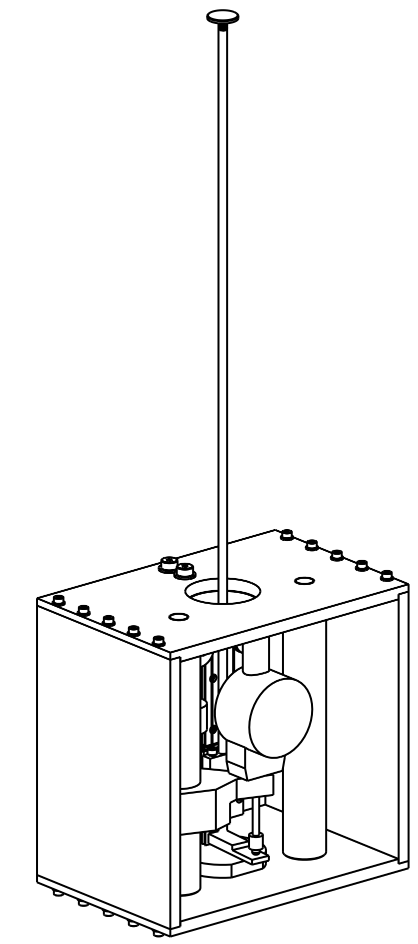
TITLE: BOM FOR MAIN ASSEMBLY

SIZE	DRAWN& DESIGN BY:	REV
C	RICARDO VANEGAS MOLLER	0

SCALE: 1:5 | DWG NO. | SHEET: 1 OF 1

APPENDIX B3: BILL OF MATERIALS (BOM) FOR BOTTOM SUBASSEMBLY





Item No.	Description	Manufacturer	P/N	Material	QTY
22	Measuring-Rod Tip		N/A	INC600	1
23	Measuring-Rod		N/A	SS316	1
24	Metric Cap Screw M4, 14mm Length, 0.7mm Pitch	McMaster	91292A038	18-8 SS	20
25	Metric DIN 125 Flat Washer M4 Screw, 9mm OD	McMaster	93475A230	18-8 SS	20
26	Top Plate, Bottom Subassembly		N/A	SS304	1
27	Metric Shldr Scrw, 8mm Shoulder Dia, M6 Thread	McMaster	90278A342	18-8 SS	3
28	Metric DIN 125 Flat Washer M8 Screw, 16mm OD	McMaster	93475A270	18-8 SS	3
29	Side Plate, Bottom Subassembly		N/A	SS304	2
30	Lock-nut for Bottom Heat-Exchanger		N/A	SS316	1
31	Bottom Plate, Bottom Subassembly		N/A	SS304	1
32	Sliding Rail Holder		N/A	SS316	1
33	Metric Cap Screw M6, 25mm Length, 1mm Pitch	McMaster	91292A138	18-8 SS	4
34	Pulley Holder		N/A	SS304	2
35	Nylon Pulley Bearing Mounted	Sava	UP2081	Nylon	2
36	Metric Cap Screw M3, 10mm Length, 0.5mm Pitch	McMaster	91292A113	18-8 SS	2
37	Metric DIN 125 Flat Washer M3 Screw, 7mm OD	McMaster	93475A210	18-8 SS	4
38	Vented Cap Screw 8-32 Thread, 3/8" Length	McMaster	93235A192	18-8 SS	4
39	Brass Counter Weights, m= 154g.		N/A	BRASS	2
40	Measuring Rod Holder		N/A	SS304	1
41	Sliding Rail	Nippon Bearing	SEBS15AYUU1-178	N/A	1
42	Metric Flat Head Screw M3, 14mm Length, .5mm	McMaster	92125A133	18-8 SS	4
43	2.0 in. Bolt		N/A	SS 304	1
44	Micrometer	Mitutoyo	543-453B	N/A	1
45	Column		N/A	SS304	2
46	Micrometer Mount	CDI	CDI6066-41	Delrin	1
47	Measuring Rod Low End		N/A	SS304	1

FRACTIONS ± 1/32
DECIMALS .XX ±.015
.XXX ±.005
HOLE Ø .XX ±.005
.XXX ±.003
ANGLES 0° 30'
BENDS ±2°
PERPEND. ⊥ .003/IN
CONCEN. ◎ .003/IN

STRAIGHTNESS &/OR FLATNESS: .005/IN
THREADS:
EXTERNAL-CLASS 2A
INTERNAL-CLASS 2B
ANGLES, BENDS, & INTERSECTIONS: 90°
MACHINED SURFACES: 63 OR BETTER

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ALL DIMENSIONS IN [ ] ARE MM
ALL DIMENSIONS IN ( ) ARE FOR REFERENCE ONLY
DO NOT SCALE DRAWING

MATERIAL: N/A
FINISH: N/A
PROJECT: GAS PRESSURE FORMING

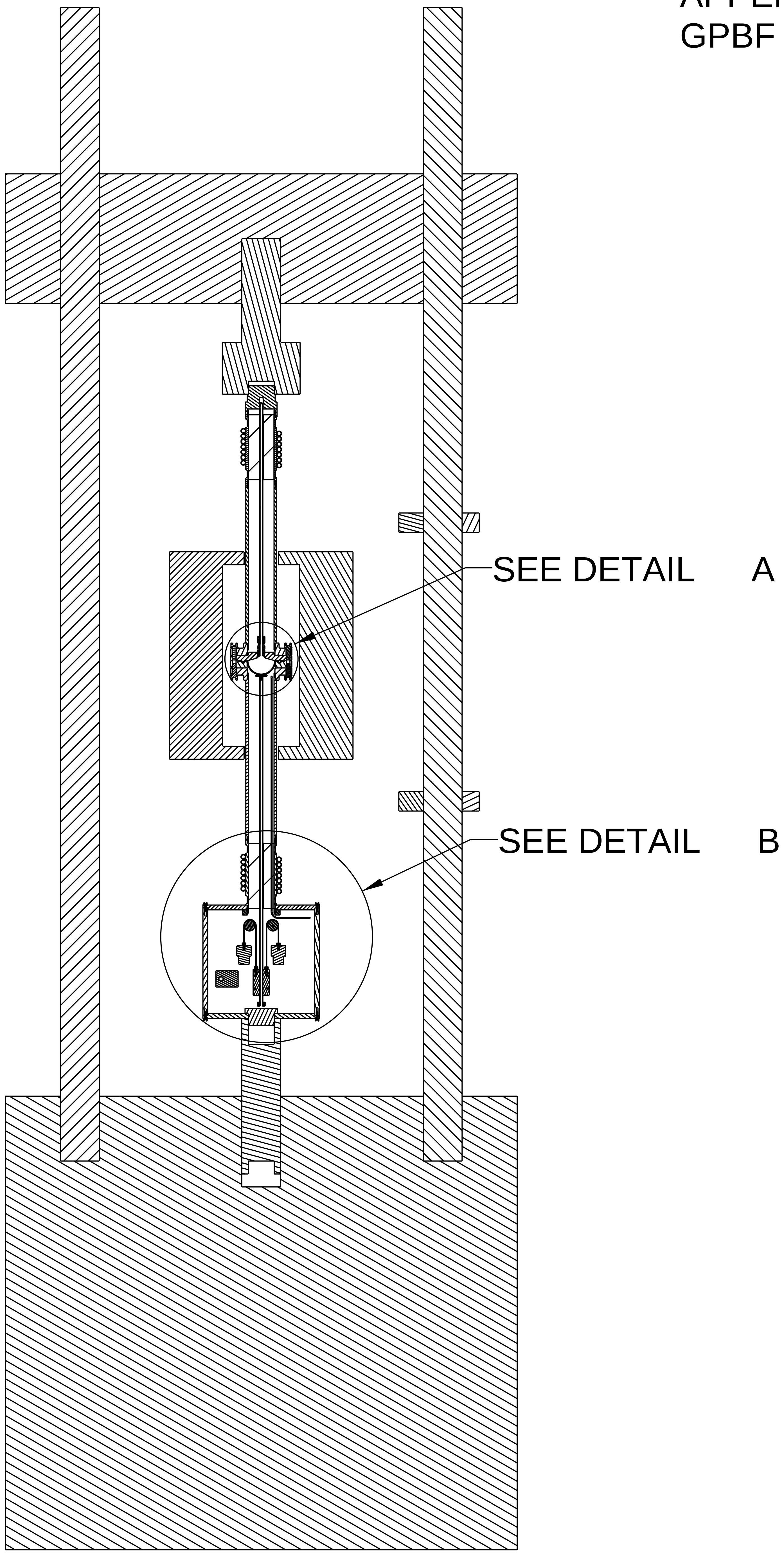
GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS

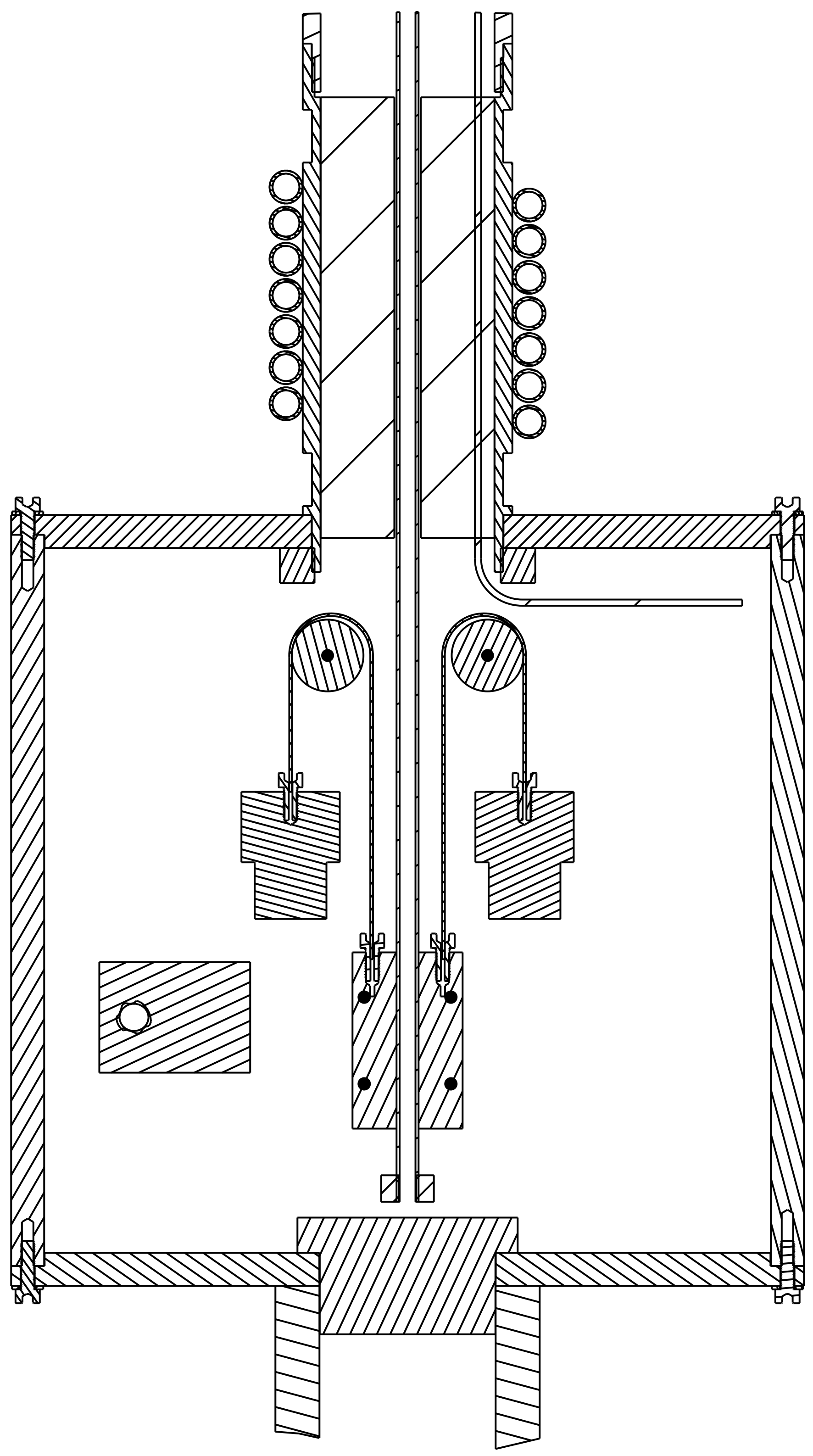
TITLE: BOM FOR BOTTOM SUBASSEMBLY

SIZE: C | DRAWN& DESIGN BY: RICARDO VANEGAS MOLLER | REV: 0

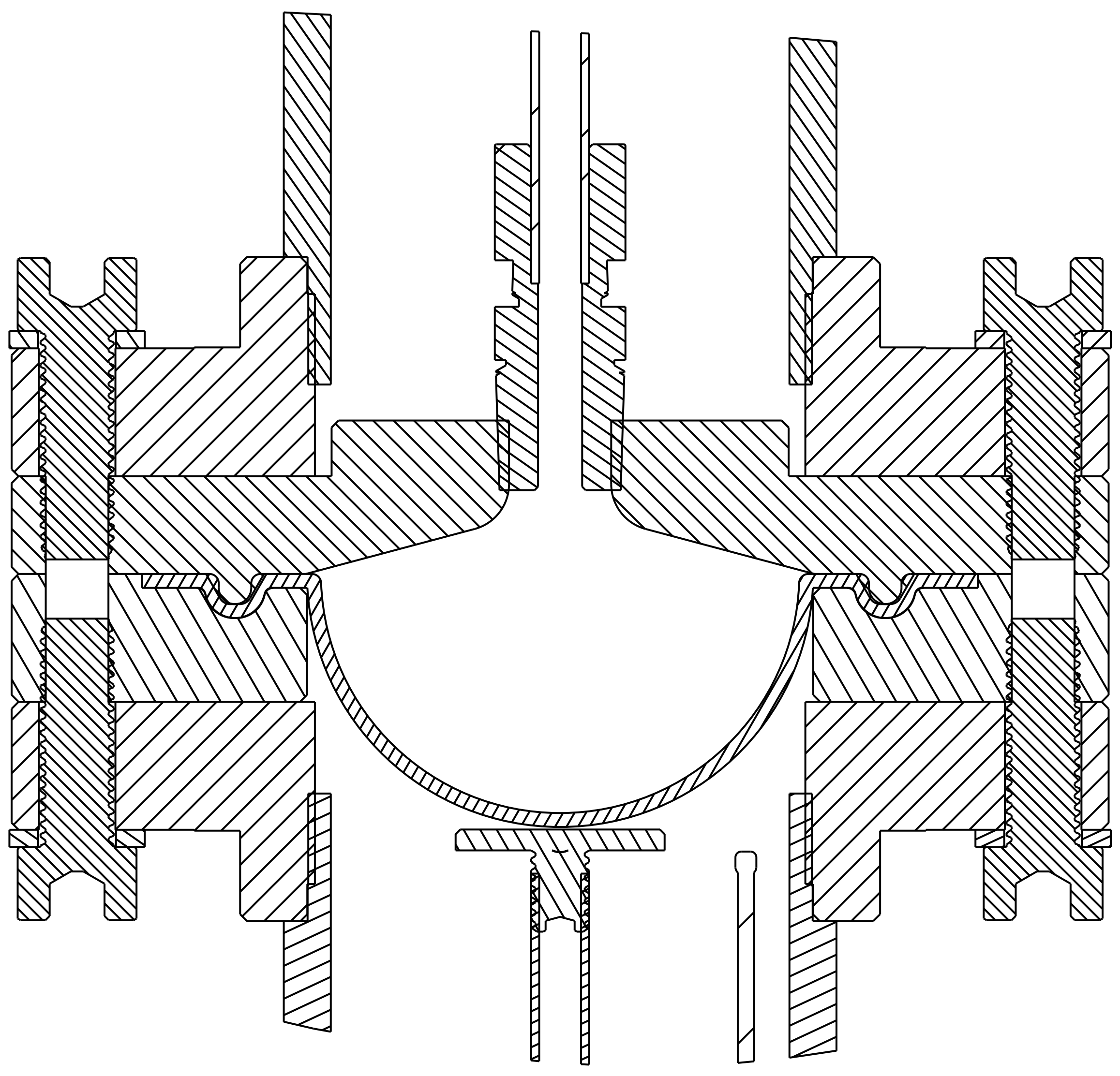
SCALE: 1:2.5 | DWG NO. | SHEET: 1 OF 1

APPENDIX B4: CROSS SECTION OF GPBF APPARATUS

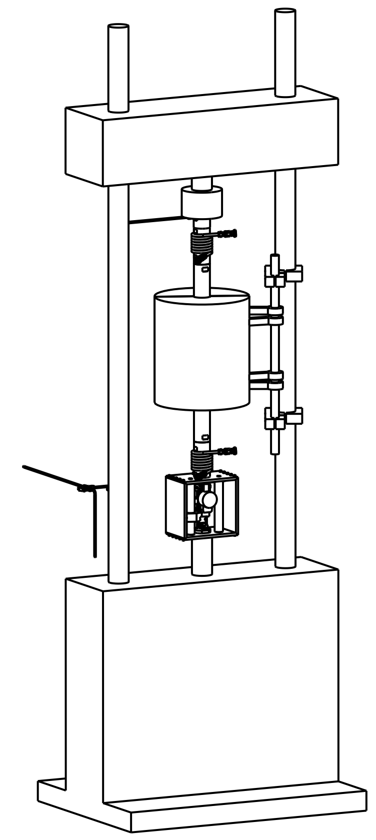




DETAIL B

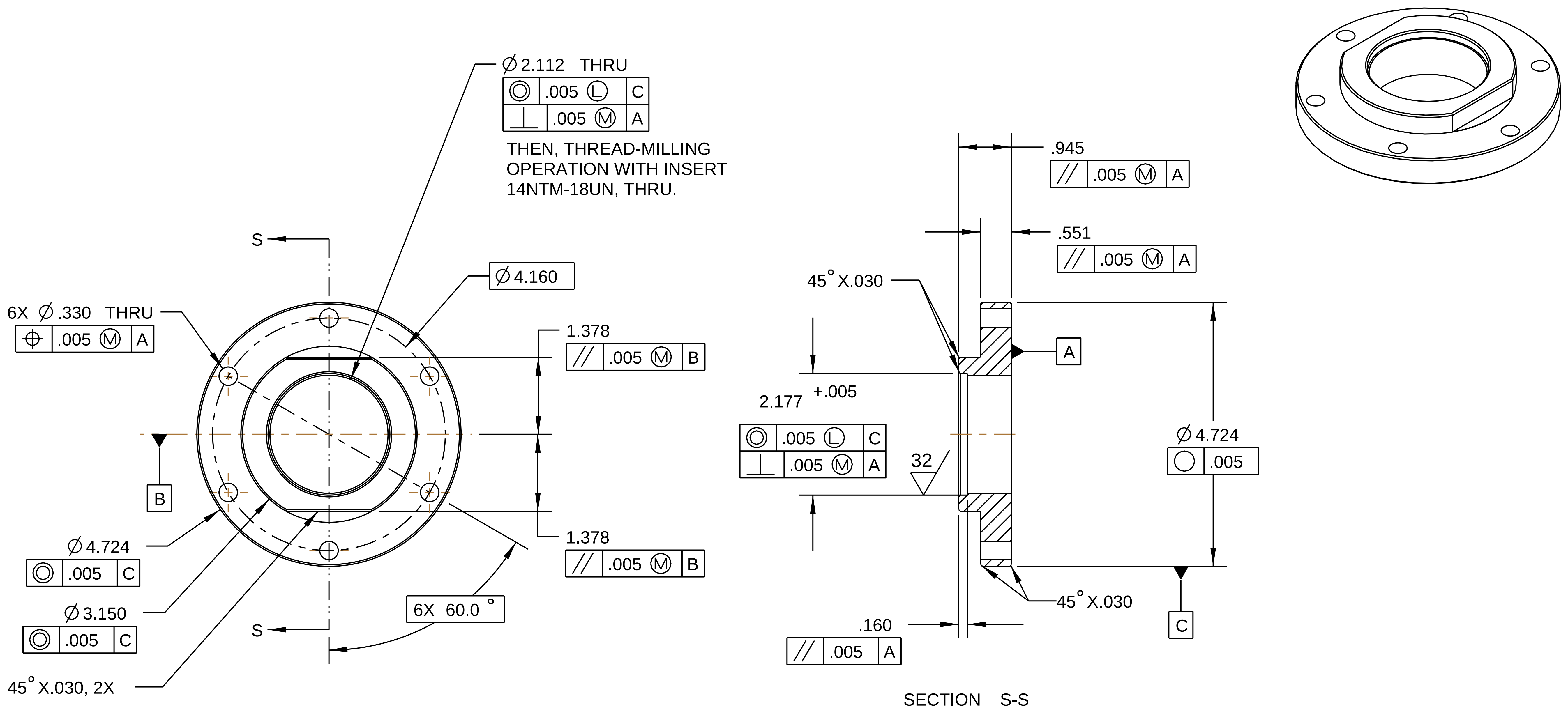


DETAIL A



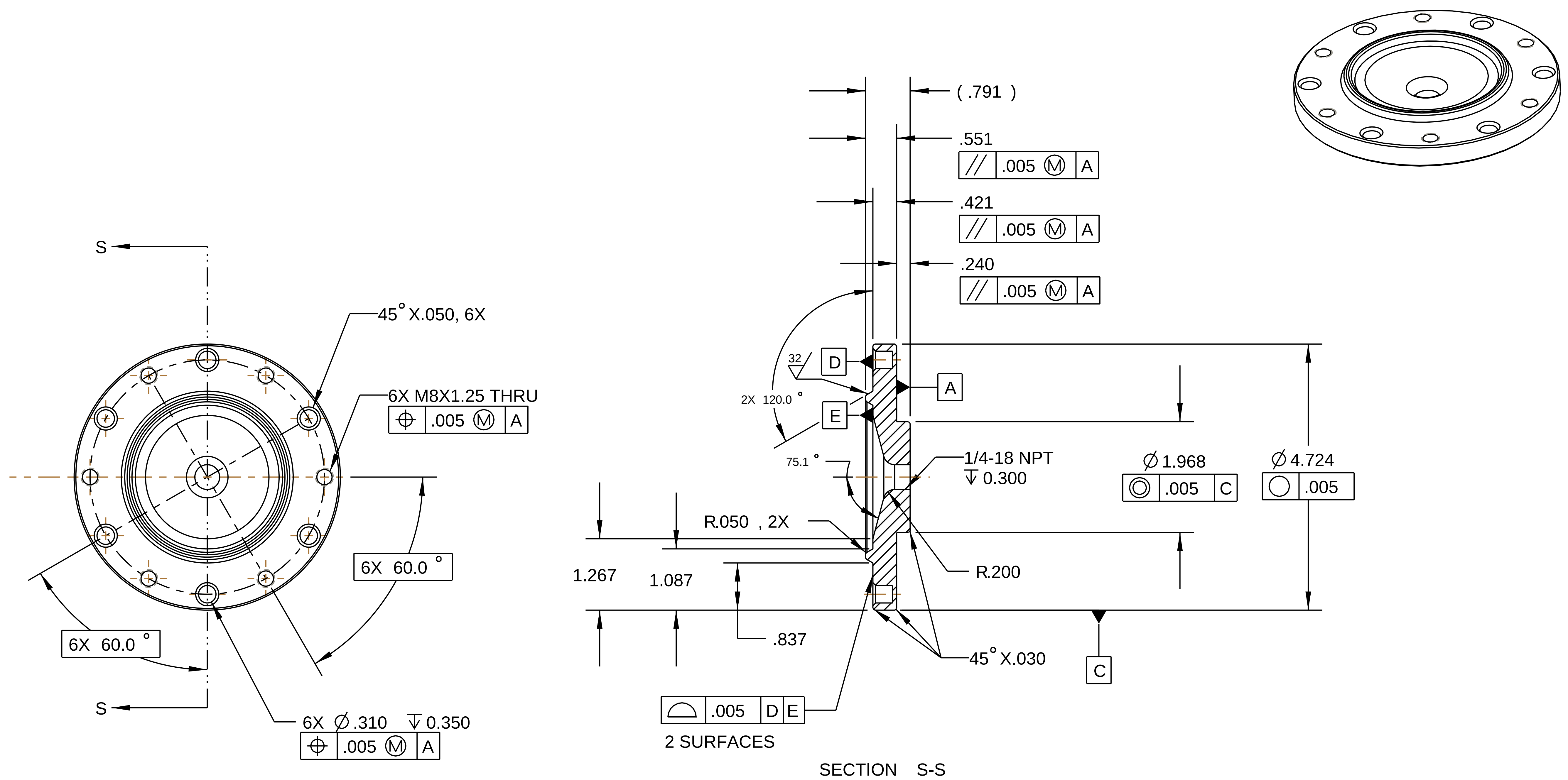
FRACTIONS ± 1/32 DECIMALS .XX ±.015 .XXX ±.005 HOLE Ø .XX ±.005 .XXX ±.003 ANGLES 0 °30' BENDS ±2° PERPEND. ⊥ .003/IN CONCEN. ◎ .003/IN	STRAIGHTNESS &/OR FLATNESS: .005/IN THREADS: EXTERNAL-CLASS 2A INTERNAL-CLASS 2B ANGLES, BENDS, & INTERSECTIONS: 90 ° MACHINED SURFACES: OR BETTER	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES ALL DIMENSIONS IN [ ] ARE MM ALL DIMENSIONS IN ( ) ARE FOR REFERENCE ONLY DO NOT SCALE DRAWING MATERIAL: N/A FINISH: N/A PROJECT: GAS PRESSURE FORMING	GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS TITLE: CROSS SECTION OF GPBF APPARATUS SIZE: C DRAWN& DESIGN BY: RICARDO VANEGAS MOLLER REV: 0 SCALE: DWG NO. SHEET: 1 OF 1

APPENDIX B5: DIE-HOLDER



FRACTIONS ± 1/32 DECIMALS .XX ±.015 .XXX ±.005 HOLE ∅ .XX ±.005 .XXX ±.003 ANGLES 0 ° 30' BENDS ±2° PERPEND. .003/IN CONCEN. .003/IN	STRAIGHTNESS &/OR FLATNESS: .005/IN THREADS: EXTERNAL-CLASS 2A INTERNAL-CLASS 2B ANGLES, BENDS, & INTERSECTIONS: 90 ° MACHINED SURFACES: 63 OR BETTER	UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES ALL DIMENSIONS IN [ ] ARE MM ALL DIMENSIONS IN ( ) ARE FOR REFERENCE ONLY DO NOT SCALE DRAWING MATERIAL: INCONEL® ALLOY 600 FINISH: REMOVE ALL BURRS AND SHARP EDGES. PROJECT: GAS PRESSURE FORMING	GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS TITLE: DIE-HOLDER SIZE B DRAWN& DESIGN BY: RICARDO VANEGAS MOLLER REV 0 SCALE: 1:2 DWG NO. SHEET: 1 OF 1

APPENDIX B6: TOP DIE-RING



FRACTIONS ± 1/32
DECIMALS .XX ±.015
.XXX ±.005
HOLE Ø .XX ±.005
.XXX ±.003
ANGLES 0 °30'
BENDS ±2°
PERPEND. ⊥ .003/IN
CONCEN. ◎ .003/IN

STRAIGHTNESS &/OR FLATNESS: .005/IN
THREADS:
EXTERNAL-CLASS 2A
INTERNAL-CLASS 2B
ANGLES, BENDS, & INTERSECTIONS: 90°
MACHINED SURFACES: 63 OR BETTER

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ALL DIMENSIONS IN [ ] ARE MM
ALL DIMENSIONS IN ( ) ARE FOR REFERENCE ONLY
DO NOT SCALE DRAWING

MATERIAL: INCONEL® ALLOY 600

FINISH: REMOVE ALL BURRS AND SHARP EDGES.

PROJECT: GAS PRESSURE FORMING

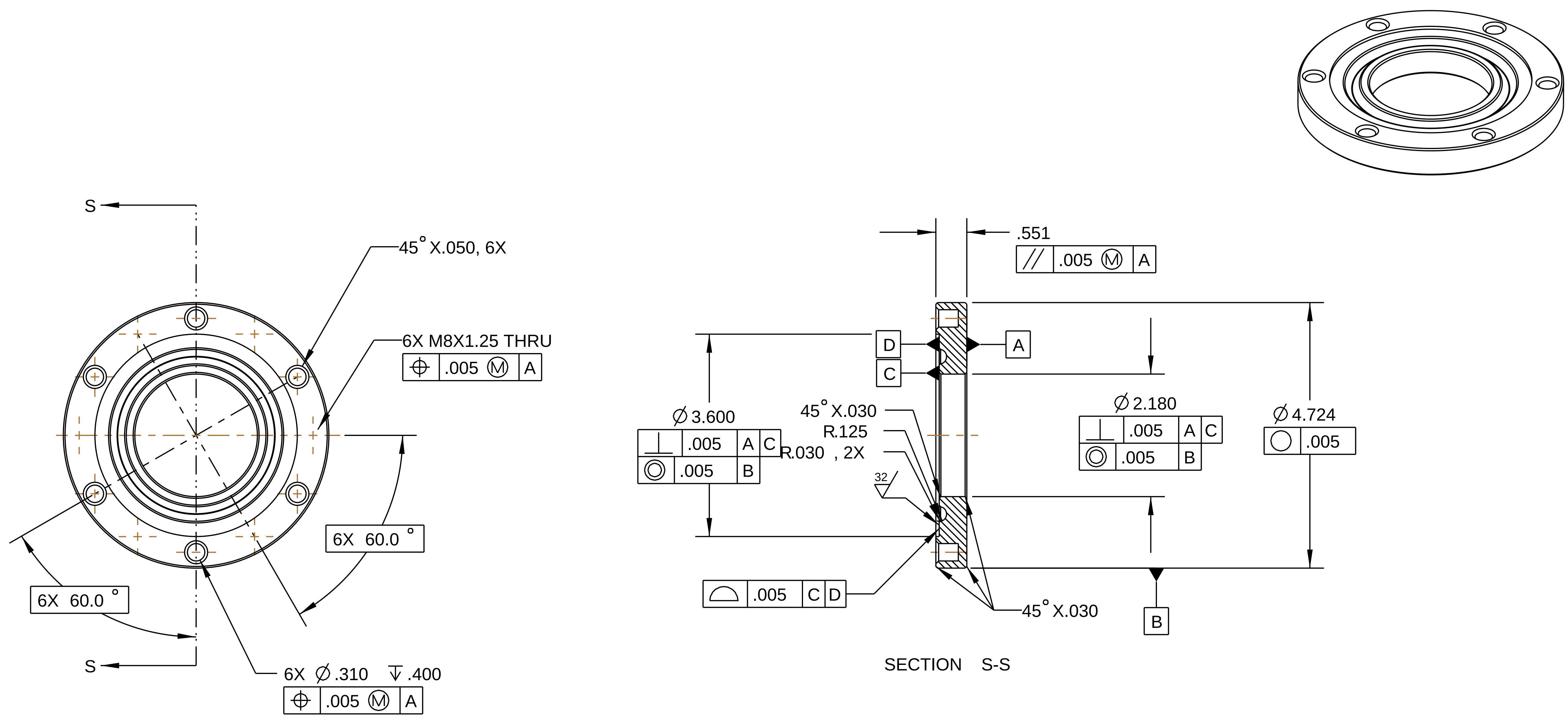
GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS

TITLE: TOP DIE-RING

SIZE	DRAWN& DESIGN BY:	REV
B	RICARDO VANEGAS MOLLER	0

SCALE 1:2 | DWG NO. | SHEET: 1 OF 1

APPENDIX B7: BOTTOM DIE-RING



FRACTIONS ± 1/32
DECIMALS .XX ±.015
.XXX ±.005
HOLE Ø .XX ±.005
.XXX ±.003
ANGLES 0° 30'
BENDS ±2°
PERPEND. .003/IN
CONCEN. .003/IN

STRAIGHTNESS &/OR FLATNESS: .005/IN
THREADS:
EXTERNAL-CLASS 2A
INTERNAL-CLASS 2B
ANGLES, BENDS, & INTERSECTIONS: 90°
MACHINED SURFACES: 63 OR BETTER

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ALL DIMENSIONS IN [ ] ARE MM
ALL DIMENSIONS IN ( ) ARE FOR REFERENCE ONLY
DO NOT SCALE DRAWING

MATERIAL: INCONEL® ALLOY 600

FINISH: REMOVE ALL BURRS AND SHARP EDGES.

PROJECT: GAS PRESSURE FORMING

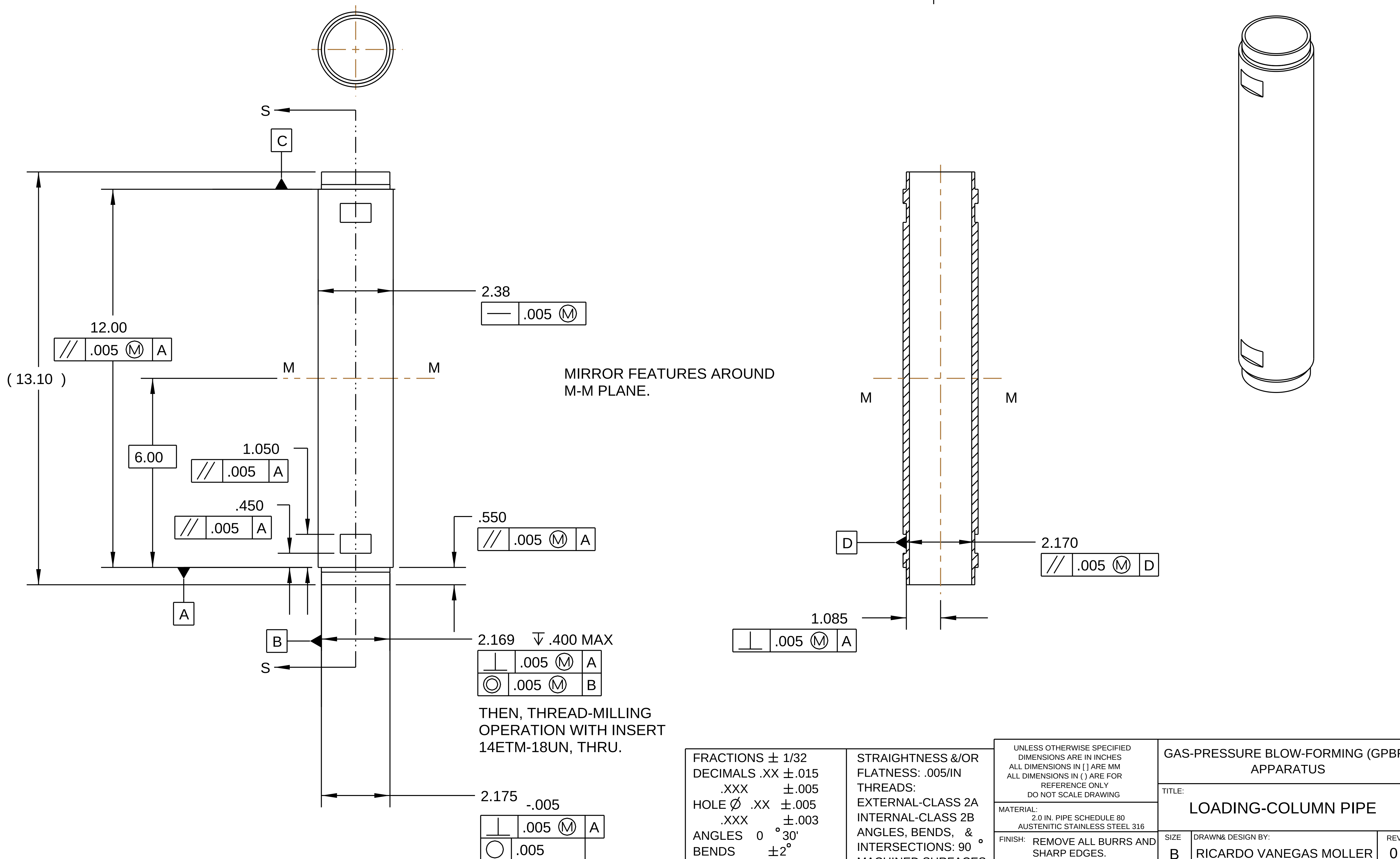
GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS

TITLE: BOTTOM DIE-RING

SIZE	DRAWN& DESIGN BY:	REV
B	RICARDO VANEGAS MOLLER	0

SCALE 1:2 | DWG NO. | SHEET: 1 OF 1

APPENDIX B8: LOADING-COLUMN PIPE



FRACTIONS ± 1/32
DECIMALS .XX ±.015
.XXX ±.005
HOLE Ø .XX ±.005
.XXX ±.003
ANGLES 0 ° 30'
BENDS ±2°
PERPEND. ⊥ .003/IN
CONCEN. ◎ .003/IN

STRAIGHTNESS &/OR
FLATNESS: .005/IN
THREADS:
EXTERNAL-CLASS 2A
INTERNAL-CLASS 2B
ANGLES, BENDS, &
INTERSECTIONS: 90 °
MACHINED SURFACES:
63 OR BETTER

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ALL DIMENSIONS IN [ ] ARE MM
ALL DIMENSIONS IN ( ) ARE FOR
REFERENCE ONLY
DO NOT SCALE DRAWING

MATERIAL:
2.0 IN. PIPE SCHEDULE 80
AUSTENITIC STAINLESS STEEL 316

FINISH: REMOVE ALL BURRS AND SHARP EDGES.

PROJECT:
GAS PRESSURE FORMING

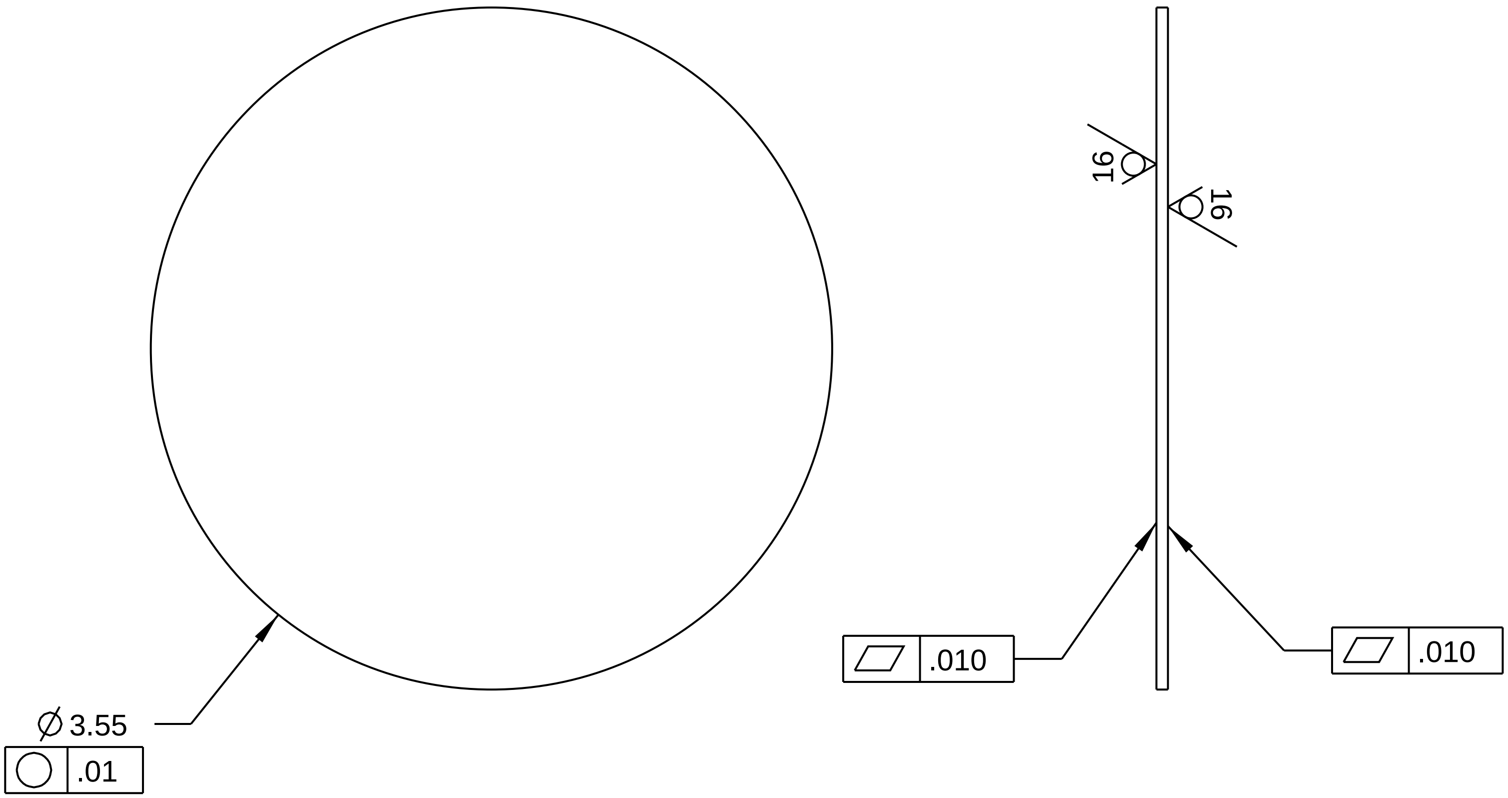
GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS

TITLE:
LOADING-COLUMN PIPE

SIZE	DRAWN& DESIGN BY:	REV
B	RICARDO VANEGAS MOLLER	0

SCALE 1:3 | DWG NO. | SHEET: 1 OF 1

APPENDIX B9: SPECIMEN



FRACTIONS ± 1/32
DECIMALS .XX ±.015
.XXX ±.005
HOLE Ø .XX ±.005
.XXX ±.003
ANGLES 0 ° 30'
BENDS ±2°
PERPEND. ⊥ .003/IN
CONCEN. ◎ .003/IN

STRAIGHTNESS &/OR FLATNESS: .005/IN
THREADS:
EXTERNAL-CLASS 2A
INTERNAL-CLASS 2B
ANGLES, BENDS, & INTERSECTIONS: 90 °
MACHINED SURFACES: 63 OR BETTER

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
ALL DIMENSIONS IN [ ] ARE MM
ALL DIMENSIONS IN ( ) ARE FOR REFERENCE ONLY
DO NOT SCALE DRAWING

MATERIAL: ALUMINUM ALLOY OR MAGNESIUM ALLOY

FINISH: REMOVE ALL BURRS AND SHARP EDGES.

PROJECT: GAS PRESSURE FORMING

GAS-PRESSURE BLOW-FORMING (GPBF) APPARATUS

TITLE: SPECIMEN

SIZE: A

DRAWN& DESIGN BY: RICARDO VANEGAS MOLLER

REV: 0

SCALE: 1:1

DWG NO.

SHEET: 1 OF 1

Appendix C

Micrometer and Bearing Components

Appendix C1: Micrometer

The following pages were taken from the Mitutoyo® catalog (www.mitutoyo.com)

ABSOLUTE Digimatic Indicator ID-C

SERIES 543 — Standard Type

FEATURES

- As compact as standard Series 2 dial indicators.
- Large, easy-to-read LCD.
- ZERO/ABS key: Allows the display to be Zero-Set at any spindle position for comparison measurements. This switch will also allow return to the absolute coordinate and display of the true position from the origin point.
- GO/±NG judgment can be performed by setting upper and lower tolerance limits. The judgment result (GO/±NG) can be displayed in full-size characters.
- The positive/negative count resulting from the spindle's up/down movement can be toggled.
- Unlimited response speed eliminates spindle over-speed errors.
- The ID-C indicator face can be rotated 330 ° to an appropriate angle for easy reading.
- With SPC data output.

SPC

ABSOLUTE®
Absolute System Patented by MITUTOYO

(Refer to the page 9 for details.)

Technical Data

Accuracy: Refer to the list of specifications (excluding quantizing error)
Resolution: 0.01mm, 0.001mm, .0005"/0.01mm, .0001"/0.001mm or .00005"/0.001mm
Display: LCD
Length standard: ABSOLUTE electrostatic capacitance type linear encoder
Max. response speed: Unlimited
Measuring force: Refer to the list of specifications
Stem dia.: 8mm (ISO/JIS type) or 3/8" (ANSI/AGD type)
Contact point: Carbide ball with M2.5x0.45 (ISO/JIS type) Carbide ball with #4-48UNF (ANSI/AGD type)
Battery: SR44 (1 pc.), **938882**
Battery life: Approx. 5,000 hours under normal use
Dust/Water protection level: IP42 or IP53 (dust-proof type)

Function

Origin-set/Preset, Zeroset, GO/±NG judgment, Counting direction switching, Power ON/OFF, Data output, inch/mm conversion (inch/mm models)
Alarm: Low voltage, Counting value composition error, Over-flow error, Tolerance limit setting error

Optional Accessory

905338: SPC cable (1m)
905409: SPC cable (2m)
902011: Spindle lifting lever (ISO/JIS type)*
902794: Spindle lifting lever (ANSI/AGD type)*
137693: Spindle lifting hook**
540774: Spindle lifting cable
125317: Spare rubber boot (for dust-proof type)
02ACA571: Auxiliary spindle spring for 25mm/1" models***
02ACA773: Auxiliary spindle spring for 50mm/2" models***
———: Backs (See page 266.)
———: Contact points (See page 264.)

*Can be used on 12mm/.5" models only.
**Can be used on 25mm/1" or 50mm/2" models.
***Required when orienting the indicator upside down.

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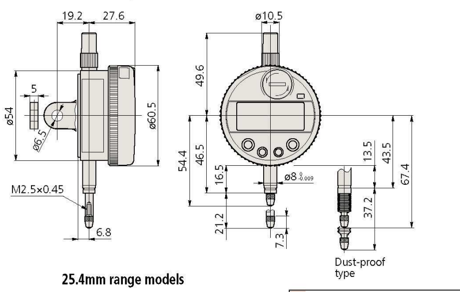
DIMENSION

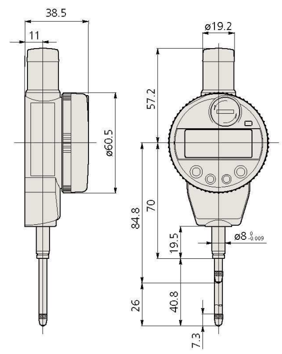
ISO/JIS Type

Unit: mm

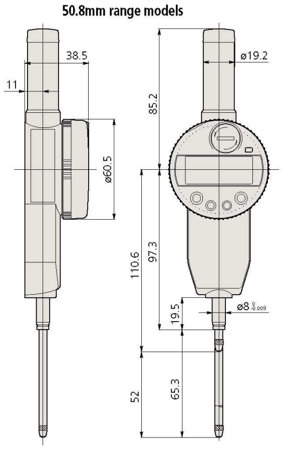
12.7mm range models



25.4mm range models



50.8mm range models



Note 1: Dimensions of the inch (ANSI/AGD Type) dial indicator partly differ from those of the metric (ISO/JIS Type) indicator.
Note 2: Inch (ANSI/AGD Type) dial indicator is provided with a stem of 3/8" dia. and #4-48UNF thread mount for the contact point.

SPECIFICATIONS

Metric

ISO/JIS type ANSI/AGD type

Resolution	**Order No.** (w/ lug, flat-back)		Range	Accuracy	Measuring force	Remarks
0.001mm	**543-250**	**543-250B**	12.7mm	0.003mm	1.5N or less	—
0.001mm	**543-257**	**543-257B**	12.7mm	0.003mm	2.0N or less	Dust-proof
0.001mm	**543-254**	**543-254B**	12.7mm	0.003mm	0.4N - 0.7N	Low measuring force
0.001mm	—	**543-450B**	25.4mm	0.003mm	1.8N or less	—
0.001mm	—	**543-460B**	50.8mm	0.006mm	2.3N or less	—
0.01mm	**543-290**	**543-290B**	12.7mm	0.005mm	1.5N or less	—
0.01mm	**543-270**	**543-270B**	12.7mm	0.02mm	0.9N or less	—
0.01mm	**543-277**	**543-277B**	12.7mm	0.002mm	2.0N or less	Dust-proof
0.01mm	**543-274**	**543-274B**	12.7mm	0.002mm	0.2N - 0.5N	Low measuring force
0.01mm	—	**543-457B**	25.4mm	0.005mm	1.8N or less	—
0.01mm	—	**543-454B**	25.4mm	0.03mm	1.8N or less	—

Inch/Metric

Resolution	**Order No.** (w/ lug, flat-back)		Range	Accuracy	Measuring force	Remarks
.00005"/0.001mm	**543-251**	**543-251B**	.5"	.00012"	1.5N or less	—
.00005"/0.001mm	**543-252**	**543-252B**	.5"	.00012"	1.5N or less	—
.00005"/0.001mm	**543-258**	**543-258B**	.5"	.00012"	2.0N or less	Dust-proof
.00005"/0.001mm	**543-259**	**543-259B**	.5"	.00012"	2.0N or less	Dust-proof
.00005"/0.001mm	**543-255**	**543-255B**	.5"	.00012"	0.4N - 0.7N	Low measuring force
.00005"/0.001mm	**543-256**	**543-256B**	.5"	.00012"	0.4N - 0.7N	Low measuring force
.00005"/0.001mm	—	**543-451B**	1"	.00012"	1.8N or less	—
.00005"/0.001mm	—	**543-452B**	1"	.00012"	1.8N or less	—
.00005"/0.001mm	—	**543-461B**	2"	.00025"	2.3N or less	—
.00005"/0.001mm	—	**543-462B**	2"	.00025"	2.3N or less	—
.0001"/0.001mm	**543-253**	**543-253B**	.5"	.00012"	1.5N or less	—
.0001"/0.001mm	—	**543-453B**	1"	.00012"	1.8N or less	—
.0001"/0.001mm	—	**543-463B**	2"	.00025"	2.3N or less	—
.0005"/0.01mm	**543-291**	**543-291B**	.5"	.0002"	1.5N or less	—
.0005"/0.01mm	**543-292**	**543-292B**	.5"	.0002"	1.5N or less	—
.0005"/0.01mm	**543-271**	**543-271B**	.5"	.0008"	0.9N or less	—
.0005"/0.01mm	**543-272**	**543-272B**	.5"	.0008"	0.9N or less	—
.0005"/0.01mm	**543-278**	**543-278B**	.5"	.0008"	2.0N or less	Dust-proof
.0005"/0.01mm	**543-279**	**543-279B**	.5"	.0008"	2.0N or less	Dust-proof
.0005"/0.01mm	**543-275**	**543-275B**	.5"	.0008"	0.2N - 0.5N	Low measuring force
.0005"/0.01mm	**543-276**	**543-276B**	.5"	.0008"	0.2N - 0.5N	Low measuring force
.0005"/0.01mm	—	**543-458B**	1"	.0002"	1.8N or less	—
.0005"/0.01mm	—	**543-459B**	1"	.0002"	1.8N or less	—
.0005"/0.01mm	—	**543-455B**	1"	.0012"	1.8N or less	—
.0005"/0.01mm	—	**543-456B**	1"	.0012"	1.8N or less	—
.0005"/0.01mm	—	**543-465B**	2"	.0016"	2.3N or less	—
.0005"/0.01mm	—	**543-466B**	2"	.0016"	2.3N or less	—

Appendix C2: Micrometer Mount

The following pages were taken from the Chicago Dial Indicator® catalog (www.dialindicator.com)

Granite Stands - Granite Stand Parts and Accessories

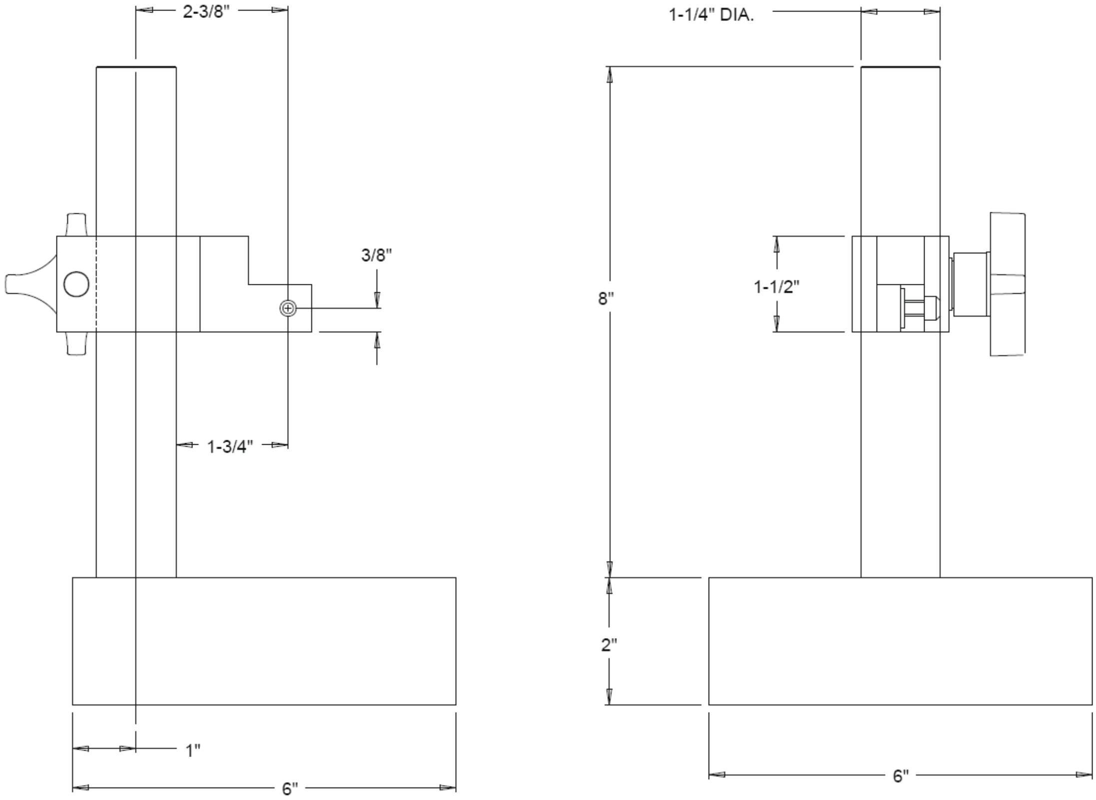
Components of CDI's comparator stands can be purchased seperately. The indicator arms will accept most manufactures gages and are designed to fit on a 1.25" diameter column. The arms can be either lug mount or stem mount, rigid or with a fine adjustment knob. The granite bases have a counterbored through hole to accept a 1/2" diameter bolt. All granite bases come with a Certificate of Accuracy, traceable to N.I.S.T..

The following chart lists the part numbers for the sub-assemblies.

EDP#	Description	Price
CDI6066-1	Granite Base Only 6" X 6" (GRADE AA)	**$116.00**
CDI6066-2	1-1/4" Dia. x 8" Tall Column	**$76.30**
CDI6066-14	Assy, Lug Mount Arm, 1-3/4" Throat Depth	**$91.50**
CDI6066-15	Assy, Stem Mount Arm, 1-3/4" Throat Depth	**$91.50**
CDI6066-40	Assy, Lug Mount Arm W/Fine Adj.	**$103.50**
CDI6066-41	Assy, Stem Mount Arm W/Fine Adj.	**$103.50**
CDI812	Granite Base Only 8" X 12" (GRADE A)	**$188.10**
CDI1812	Granite Base Only 12" X 18" (GRADE A)	**$312.50**
CDI812-2	1-1/4" Dia. x 12" Tall Column	**$82.55**
CDI1812-2	1-1/4" Dia. x 18" Tall Column	**$95.10**
CDI1812-3	1-1/4" Dia. x 24" Tall Column	**$139.00**
CDI812-15	Assy, Lug Mount Arm W/Fine Adj. 5" Throat Depth	**$111.80**
CDI812-26	Assy, Stem Mount Arm W/Fine Adj. 5" Throat Depth	**$111.80**
CDI812-23	Assy, Lug Mount Arm, 4-5/32" Throat Depth	**$100.60**
CDI812-24	Assy, Stem Mount Arm, 4-5/32" Throat Depth	**$100.60**

* Prices are subject to change without notice. To order or for further information, please contact our sales department.

GRANITE BASE 6"X6", P/N: 6066



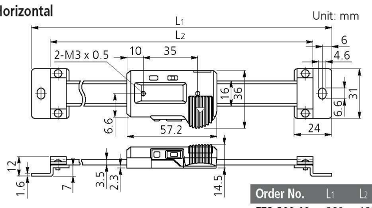
Appendix C3: Computer Hardware Interface

The following pages were taken from the Mitutoyo® catalog (www.mitutoyo.com)

Mitutoyo

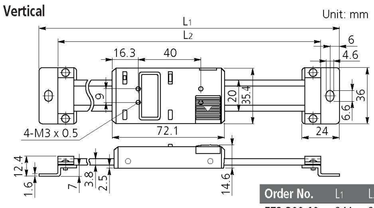
Dimensions

Horizontal

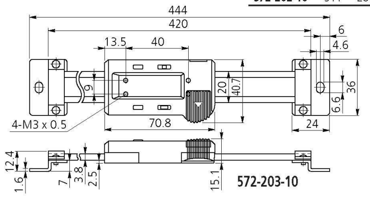


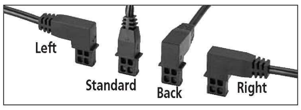
Order No.	L_1	L_2
572-200-10	209	185
572-201-10	209	235
572-202-10	311	287

Vertical



Order No.	L_1	L_2
572-300-10	244	220
572-301-10	294	270
572-302-10	344	320
572-303-10	444	420





OPTIONAL ACCESSORIES

Order No.	Description
959143	Data Hold Unit
905338	SPC cable (1m, standard)
905409	SPC cable (2m, standard)
905689	SPC cable (1m, L-shape, back)
905690	SPC cable (2m, L-shape, back)
905691	SPC cable (1m, L-shape, right)
905692	SPC cable (2m, L-shape, right)
905693	SPC cable (1m, L-shape, left)
905694	SPC cable (2m, L-shape, left)
959149	SPC cable with data switch (1m)
959150	SPC cable with data switch (2m)

Digimatic Display Units

SERIES 572 — Remote Display Counters with Bright LED for Digimatic Scale Unit

SD-D1 Single-function type Digimatic Display Unit

SD-D2 Multi-function type Digimatic Display Unit

The Digimatic Display Unit offers a large LED display for a Digimatic Scale Unit. The bright LED readout is ideal for low-light situations or when the scale unit must be inserted into an area where its own display cannot be viewed directly. Two types of single-function and multi-function are available on the Digimatic Display Unit.

SPECIFICATIONS

Metric

Model No.		SD-D1	SD-D2
Order No.	100V AC	572-001	572-021
	110V AC	572-001A	572-021A
	120V AC	572-001D	572-021D
	240V AC	572-001E	572-021E
Scale input port		1	1
Display		6-digit green LED	6-digit green LED
Functions		• Zero-setting • SPC data output • Error alarm	• Zero-setting • SPC data output • Error alarm • Presetting • GO/±NG judgment • GO/±NG output • Counting direction switching
Power supply		9V DC, 500mA (via AC adapter)	9V DC, 500mA (via AC adapter)
Dimensions		200(W)x120(D) x66(H)mm	236(W)x120(D) x66(H)mm
Mass		1.1kg	1.3kg

Inch/Metric

Model No.		SD-D1E	SD-D2E
Order No.	100V AC	572-011	572-031
	110V AC	572-011A	572-031A
	120V AC	572-011D	572-031D
	240V AC	572-011E	572-031E

DIGIMATIC SCALE UNITS

Appendix C4: Computer Software Interface

The following pages were taken from the GageWay™ catalog (www.microridge.com)

GageWay™ SM

Connect Single Mitutoyo Gage
to an RS232 or USB Port

User's Guide

MicroRidge
"The Interface Solutions Company™"
PO Box 3249 • Sunriver, OR 97707-0249
541.593.1656 • FAX 541.593.5652
sales@microridge.com • www.microridge.com

Table of Contents

Revised 8-8-2006

The GageWay SM is an easy-to-use interface designed to connect a Mitutoyo or Mitutoyo compatible gage to an serial or USB port. A serial communications test program (ComTestSerial) is included so that you can test and become familiar with the operation of the GageWay SM. When using the USB version of the GageWay SM, the USB connection looks like a standard RS232 serial port to your PC application.

GageWay SM
with RS232 Output

GageWay SM
with USB Output

Features and Benefits of the GageWay SM

- No baud rate or communication parameters setup required. The GageWay SM is pre-configured to operate at 9600-N-8-1.
- Initiate single and continuous readings with the read button on the gage, an optional foot or hand switch, or a simple computer command.
- An LED flashes when a gage reading has been obtained.
- Plugs directly into a standard 9-pin PC serial port or USB port.
- Powered by the serial port or USB port. No external AC adapter is required.
- Firmware (software program in the GageWay SM) can be upgraded via the serial or USB port. Check

the MicroRidge web site at www.microridge.com for software updates.

- ComTestSerial communications test program included with the GageWay SM.
- Available with any cable length from 12 to 72 inches. Standard lengths are 18 and 72 inches.
- Supports Mitutoyo gages and any gage that provides a standard Mitutoyo output (CDI, Federal µMaxum, etc.).
- Standard Mitutoyo cables can be used without modification. These Mitutoyo gage cables can be purchased from any Mitutoyo dealer or can be purchased from MicroRidge.
- If you are using CDI or Federal gages with a Mitutoyo output, you may need to purchase the gage cables from MicroRidge.

Driver Installation for USB Version

Before you connect the USB version of the GageWay SM to your PC, you must install the USB and virtual serial port drivers. These drivers are located on the CD that you received with the GageWay SM. After installing the drivers, connect the GageWay SM to a USB port. Once the GageWay SM is connected, you will get a message about new hardware found.

Operation

To become familiar with the operation of the GageWay SM, we suggest you follow the steps outlined below. You can check communications with the GageWay SM even if you do not have a gage connected to the interface.

1. Connect the GageWay SM to a serial or USB port. If you have purchased a GageWay SM with an RS232 connector and do not have a serial port on your PC, refer to "My Computer Does Not Have a Serial Port" on page 6.
2. Start the ComTestSerial communications program.
3. If necessary, change the serial port number. The Registry Description in the Select & Configure Serial Port dialog for the USB version will have a description similar to \Device\VCP0. In order to use the USB version, you must select the virtual serial port that was created for the currently connected GageWay SM.
4. Use the computer commands on page 4 and the command buttons at the bottom of the ComTestSerial window to test the communications with the GageWay SM.

When the GageWay SM is powered up, the LED will blink about 6 times. When the blinking stops, the GageWay SM is ready to receive commands and send data to the PC.

The RS232 version of the GageWay SM is powered by the serial port handshake lines. Power up and power down of the GageWay SM is performed by the application controlling the serial port handshake lines. Refer to page 5 for more details.

The USB version of the GageWay SM is powered by the USB port and will be powered up when the GageWay SM is connected to a USB port.

Computer Commands

The GageWay SM can be controlled with a set of computer commands. You should test these commands with ComTestSerial so that you fully understand the response and the format of the response.

The user commands that consist of a letter can be upper or lower case. To request a reading you can send R or r. A carriage return (enter key) is not required at the end of any of the commands. If you send an invalid command, the command will be discarded by the GageWay SM.

User commands (commands can be upper or lower case):

R Read gage.

B Begin continuous gage read.
S Stop continuous gage read.

C Begin continuous gage read when read switch (foot switch, hand switch, read button on gage, etc.) is pressed and held.
D Stop (disable) continuous gage read when the read switch is released.

H Display a list of the computer commands.
L Turn the LED on for 50 milliseconds (msec).
V Version information.
Z Reset to power up configuration. This will also disable the continuous read that was controlled by a remote read switch. The LED will flash 4 times when this command is received.
* Copyright information.

How the GageWay SM is Powered

The RS232 version of the GageWay SM is designed to draw its power from the serial port and does not require an external AC adapter. On the standard serial port there are 2 handshake lines that can be used to supply power to devices that have very low power needs. On the standard 9-pin PC serial port, the 2 pins that are used are pin 4 (DTR) and pin 7 (RTS). In order for your application to use the GageWay SM, one or both of these pins must be high. Typically when an application opens a serial port, the application sets both of these pins to the high state. You can manually set these handshake pins high and low when testing the GageWay SM with the ComTestSerial communications program.

The USB version of the GageWay SM is powered directly by the USB port and it does not matter whether the handshake lines are high or low.

Output Data Format

The data format of a reading from a Mitutoyo device is fixed and cannot be modified by the user. The GageWay SM sends the measurement left justified and the measurement is terminated with a carriage return. There are no leading, trailing or embedded blanks in the measurement string. The length of the measurement string will vary based on the number of digits in the measurement. A few examples are shown below.

1.3265

.1455

-.5725

13.26

My Computer Does Not Have a Serial Port

This topic is only pertinent if you are trying to connect an RS232 version of the GageWay SM to your PC. If you have purchased the RS232 version and really need the USB version, contact your dealer or MicroRidge Systems.

Many of the computers that are being sold today do not contain any RS232 serial ports. If your computer does not have any serial ports, it will have several USB ports. You will need to obtain a USB to serial converter cable in order to connect the RS232 version of the GageWay SM to your PC. This cable will convert one of your USB ports to a serial port. These USB to serial cables are available directly from MicroRidge at a very reasonable price.

Why Do I Need an Interface?

We often get asked "Why do I need to purchase a gage interface to connect my gage to a PC?" The Mitutoyo compatible gages use a signaling method referred to as clocked serial.

The clocked serial data is not sent at a constant rate like RS232 data; therefore, the Mitutoyo signals require special signal processing to convert them into a standard RS232 format. Remember that when using the USB version of the GageWay SM, the firmware in the GageWay SM and the USB drivers make this USB interface look like a regular RS232 serial port to your PC application.

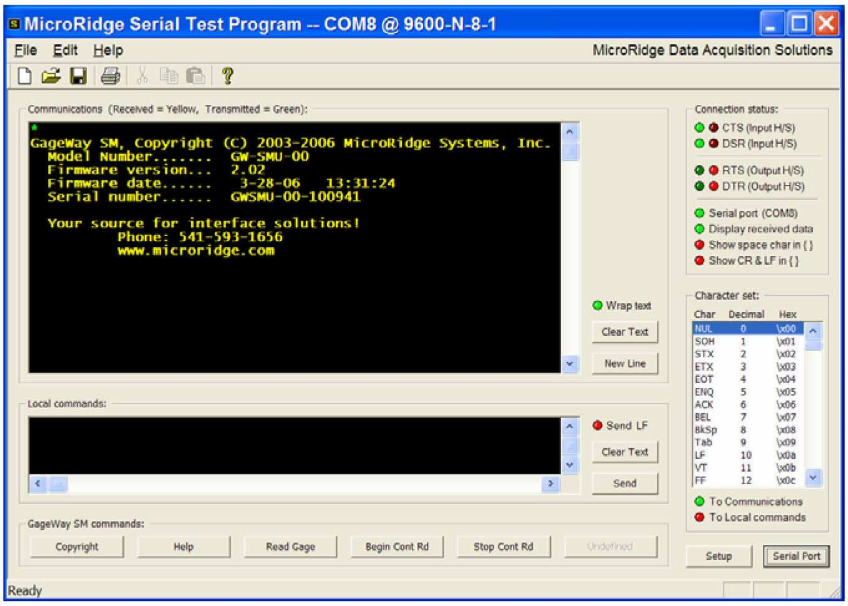
There are a few calipers and digital indicators that have an RS232 output; however, one should carefully analyze the cost before purchasing the RS232 ready devices.

You must consider the gage cables to be a consumable item, and factor gage cable replacement into the cost of your measurement system. People have reported that gage cable consumable rates may be measured in days, weeks or months. Another limitation with RS232 ready devices is that the range of products available is small when compared to the products with a Mitutoyo compatible output.

ComTestSerial Communications Test Program

A serial communications test program is included on a CD with the GageWay SM. This test program is much easier to use than the HyperTerminal (hypertrm.exe) included with Windows. The default communication parameters in ComTestSerial match those of the GageWay SM. The only setting you may have to change is the serial port selection. By default, COM1 is selected. If your GageWay SM is connected to a different serial port, press the Serial Port button in the lower right corner and select the appropriate port.

ComTestSerial can be loaded on as many computers as required. To install this test program, select the ComTestSerial installation option on the CD included with your GageWay SM. ComTestSerial is designed for use on Windows 2000, XP and later. MicroRidge does not support the use of ComTestSerial on Windows 9x systems.



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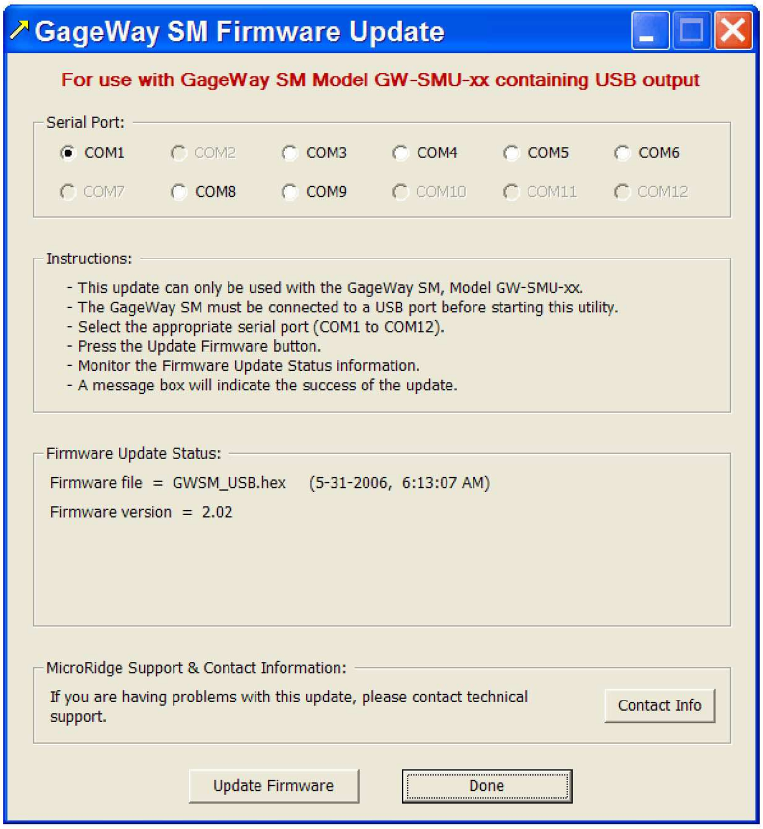
Firmware Updates

The firmware in the GageWay SM can be updated via the serial or USB port. Firmware updates are posted on the MicroRidge web site at www.microridge.com.

To update the firmware, download the appropriate update and run the file to install the program and new firmware files on your PC. If you select the default installation, the software will be installed in C:\GageWaySM_Firmware. Connect the GageWay SM to your serial or USB port and run the program from the shortcut installed on your desktop. Follow the instructions shown in the program. To remove the update software from your PC, select the uninstall option from the Start menu or use the Add or Remove Programs icon in the Control Panel



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About MicroRidge

MicroRidge designs and builds hardware and software solutions for RS232, USB and network data acquisition. We offer a full range of interfaces that support digital gages (calipers, micrometers, digital indicators, etc.) and RS232 devices. Interface products include the GageWay SM, GageWay Series and GageWay wireless systems. Our WedgeLink keyboard wedge family of products include both software and hardware wedges.

Sales & Technical Support

MicroRidge provides full technical support for all of its products. If you are having problems or need more information, please contact us.

Phone:

Sales	541-593-3500
Support	541-593-1656
Main Office	541-593-1656
Fax	541-593-5652

Email:

Sales	sales@microridge.com
Support	support@microridge.com
Info	info@microridge.com

Web: www.microridge.com

MicroRidge office hours are from 8:00 am to 4:30 pm Pacific time.

Appendix C5: Sliding Rail

The following pages were taken from the Nippon Bearing Co.© catalog (/www.nbcorporation.com)

NEW ITEM

NB

SLIDE GUIDE

SEBS-B type

Miniature Slide Guide Series with Retained Ball now Offers Complete Selection

Certificate No.958188

NIPPON BEARING CO., LTD.

Expanded Selection for Miniature Slide Guide Series
Full Selection Available for Retained Ball Type

Wide type of Miniature Slide Guide, providing greater allowable moment, is now available with retained ball structure. Due to this addition, full selection has been completed allowing for freedom of choice for the right component in your application.

STRUCTURE AND ADVANTAGES

NB's slide guide SEB type consists of a block and a guide rail, both of which have two precision ground raceway grooves. The block consists of a main body, balls, and return caps. This retained ball type has a retainer which prevents ball bearings from escaping when block is remove from rail.

Retained Balls

With the retained balls, the guide block may be removed from the rail without the balls falling out. This makes dis-assembly and re-assembly work easier.

All Stainless Steel Type (SEBS-BM/BYM Type)

All components are made of stainless steel. The return caps are now metallic and this increases usage versatility under special environments such as high temperature, clean room, or vacuum.

Compact Design

The two raceway and four-point contact structure of the SEB types minimize its height and give further advantage installation with limited space and reduces overall height.

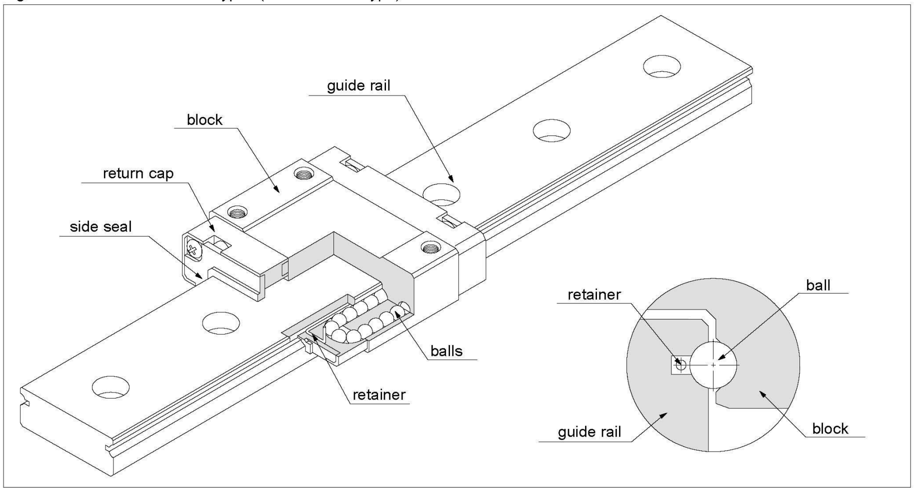
High Moment Loads

With the wide and long types an increase of moment capacity is realized. This permits for the use of "single" block designs possible.

Tapped-Hole Rail Types ("-N")

Slide guides with counter bore holes are standard and the tapped holes ("-N") are available upon request.

Figure 1 Structure of SEBS-B Types (Retained Ball Type)



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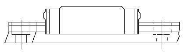
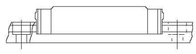
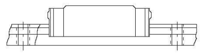
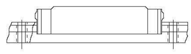
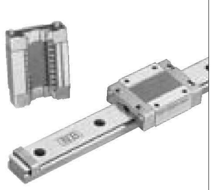
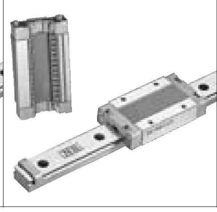
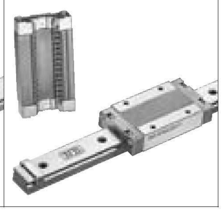
TYPES

NB Miniature Slide Guide (SEB Type) series is categorized accordings to the width and length of block, the material of block and rail, the material of return cap and the rail installation method as shown in Table 1. Each type can be also offered with or without Side Seals.

Table 1 Types

		standard block standard rail (w/counter bore)	long type block standard rail (w/counter bore)	standard block N type rail (w/tapped hole)	long type block N type rail (w/tapped hole)
					
wide type (p.7)	regin return cap	SEBS-WB type NEW 	SEBS-WBY type NEW 	SEBS-WB-N type NEW 	SEBS-WBY-N type NEW 
standard type (p.9)	regin return cap	SEBS-B type 	SEBS-BY type 	SEBS-B-N type 	SEBS-BY-N type 
	stainless return cap	SEBS-BM type 	SEBS-BYM type 	SEBS-BM-N type 	SEBS-BYM-N type 

ACCURACY

The SEB slide guides are available in two grades of accuracy: high-grade and precision-grade (P).

Table 2 Accuracy unit/mm

accuracy grade	high	precision
accuracy symbol	none	P
allowable dimensional difference in height H	±0.020	±0.010
paired difference for height H	0.015	0.007
allowable dimensional difference in width W	±0.025	±0.015
paired difference for width W	0.020	0.010
Running parallelism of surface C to surface A	Refer to Fig.2 & 3	
Running parallelism of surface D to surface B		

The difference of above pairs are applied to multiple number of blocks on the same rail. When the difference of height (H) of a pair on different rails is required, please indicate the number of rails in the part number. (Please refer to the "Part Number Structure" for furher details.)

Figure 2 Accuracy

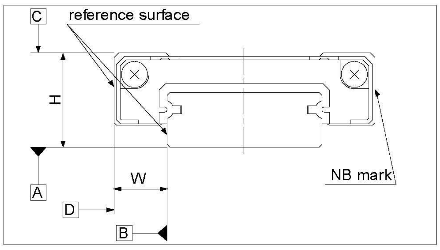
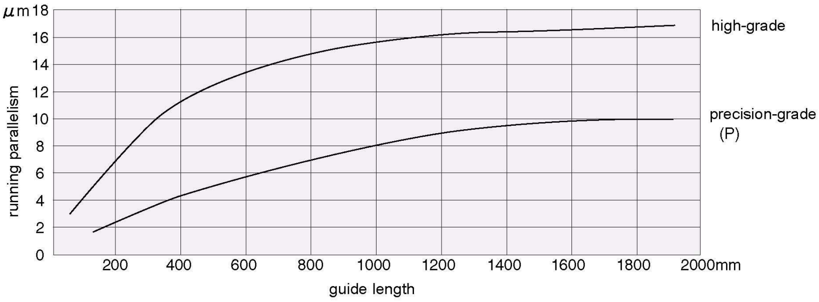


Figure 3 Motion Accuracy



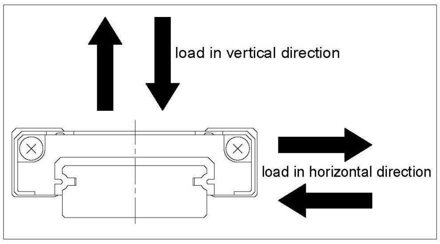
RATED LOAD

The load rating for SEB Type slide guides depends upon the direction of load.

Table 3 Load Rating

		retained ball types	standard types
basic dynamic load rating	vertical	1.00×C	1.00×C
	horizontal	0.89×C	1.13×C
basic static load rating	vertical	1.00×Co	1.00×Co
	horizontal	0.84×Co	1.19×Co

Figure 4 Direction of Load



PRE-LOAD

SEB slide guides are available with a standard pre-load (no suffix), light pre-load (T1), and a positive-clearance (T0).

Table 4 Pre-Load Symbol and Radial Clearance unit/μm

size	type of pre-load and its symbol		
	clearance	standard	light
	T 0	none	T 1
5W	+1～+3	−1～0	−
7W	+3～+6	−3～0	−4～−2
9W			
12W			
15W	+4～+8		−7～−3
5	+1～+3	−1～0	−
7	+3～+6	−3～0	−4～−2
9			
12			
15	+4～+8		−7～−3
20			

Table 5 Operating Conditions and Pre-Load

pre-load	symbol	operating conditions
clearance	T0	Smooth movement is crucial. The installation tolerance is to be absorbed.
standard	none	Minute vibration is applied. High-precision movement is required. A moment in a given direction is applied.
light	T1	Light vibration is applied. A slight torque is applied. When moment is applied.

RAIL LENGTH

Slide guides with most commonly used lengths are available as standard. Unless otherwise specified, the distance to the first mounting hole (N) from one end of the rail will be located within the ranges listed in Table 6 for slide guides with non-standard lengths satisfying the following equation.

$$L = M \cdot P + 2N$$

L : length (mm) N : distance to the first hole from the end of the rail (mm)
M : number of pitches P : hole pitch (mm)

Figure 5 Rail

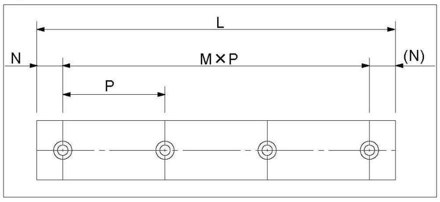


Table 6 Range of N dimension unit/mm

size	N	
	more	less
5W	3	10
7W	4	19
9W		
12W	5	25
15W		
5	3	10.5
7		
9	4	14
12		16.5
15		24
20	6	36

INSTALLATION

Shapes of mounting planes

Slide Guides are generally mounted by pushing the reference surface of the rail and block against the shoulder of the mounting surface.
An escape groove should be provided at the corner of the shoulder in order to avoid interference with the corner of the rail or block.

Figure 6 Mounting Reference Surface Shapes-1

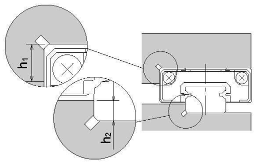


Figure 7 Mounting Reference Surface Shapes-2

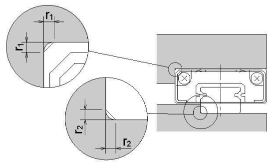


Table 7 Shoulder height of mounting unit:mm

part number	h_1	h_2
5W	2	1
7W	3	1.5
9W		2.5
12W	4	
15W	5	
5	2	1
7	2.5	
9	3	1.5
12	4	2
15	5	3.5
20		5

Table 8 Maximum corner radius unit:mm

part number	r_1	r_2
5W	0.3	0.3
7W		
9W		
12W		
15W		
5	0.3	0.3
7		
9		
12		
15		
20	0.5	0.5

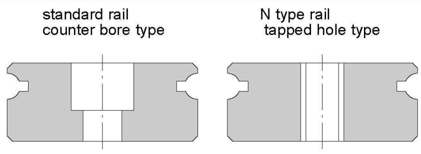
Recommended tightening torque

The bolts used to secure the rail should be tightened using a torque wrench. The recommended torque values are given in Table 9.

Table 9 Recommended Tightning Torque unit/N・m

size	standard rail		N type rail	
	bolt size	recommended torque	bolt size	recommended torque
5W	M2.6	0.6	M3	1.0
7W	M3	1.0	M4	2.3
9W				
12W	M4	2.3	M5	4.6
15W				
5	M2	0.3	M2.6	0.6
7			M3	1.0
9	M3	1.0	M4	2.3
12				
15			M5	4.6
20	M5	4.6	M6	10.0

Figure 8 Shapes of Rail



MOUNTING BOLTS

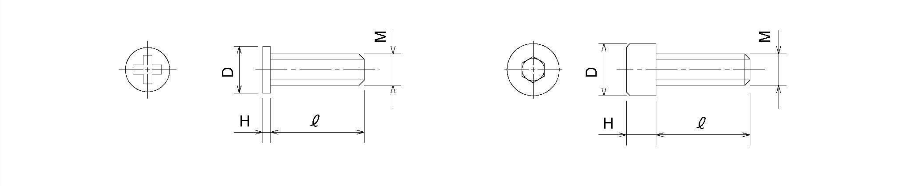
Small bolts for the SEB type are available from NB.

Table 10 Mounting Bolt (stainless steel) unit/mm

type	type	bolt size	D mm	H mm	pitch mm	length ℓ mm
custom screw	fig.9- ①	M2	3	0.6	0.4	6
cap screw	fig.9- ②	M2	3.8	2	0.4	4,5,6,8,10
		M2.6	4.5	2.6	0.45	4,5,6,8,10

Custom screws for SEBS5A rails come with the rail.

Figure 9 Mounting Bolts (Sizes 5 & 7 only)



LUBRICATION

NB Slide Guides contain a quality lithium soap-based grease before they are shipped, and can be used as delivered. As use continues, lubricate them as required depending on operating conditions.

Under special use environments like clean room or vacuum, NB Slide Guides are available without grease or with special instructed grease applied upon request.

SEB Slide Guides retained ball type may be lubricated with ease as shown in Fig.10 (NB patented feature). NB offers two standard types of grease in syringe type applicators as shown in Table 11.

Figure 10 Greasing Method.

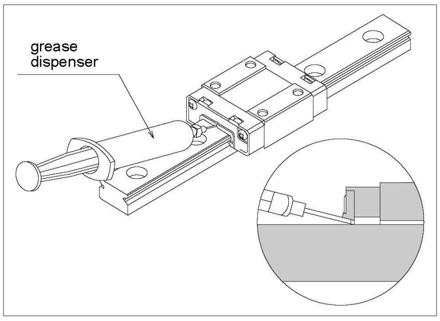


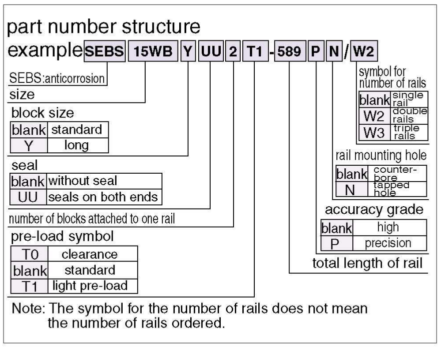
Table 11 Type of Grease

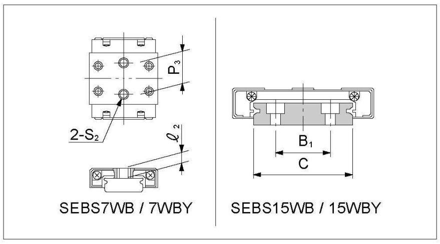
use	name of grease	contents
general	Multemp PS No.2 (Kyodo Yushi)	10g
low dust	K grease (NB)	10g

NB

NEW

SEBS-WB/SEBS-WBY Type

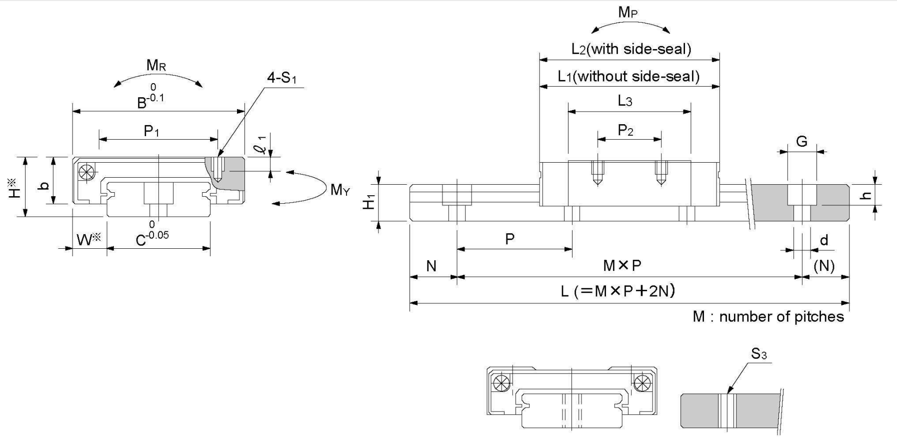




part number	assembly dimensions H	W	block dimensions B	L_1	L_2	P_1	P_2	S_1	ℓ_1	L_3	P_3	S_2	ℓ_2	b
	mm	mm	mm	mm	mm	mm	mm		mm	mm	mm		mm	mm
SEBS 5WB	6.5	3.5	17	21.3	21.7	–	6.5	M3	2.3	14.3	–	–	–	5
SEBS 5WBY				27.3	27.7		11			20.3				
SEBS 7WB	9	5.5	25	31.4	31.4	19	10		2.8	20.2	12	M4	3.5	7
SEBS 7WBY				40.1	40.1		19			28.9	18			
SEBS 9WB	12	6	30	38.5	38.5	21	12		3	26.3	–	–	–	9
SEBS 9WBY				50.5	50.5	23	24			38.3				
SEBS 12WB	14	8	40	42.6	43	28	15		3.6	29	–	–	–	11
SEBS 12WBY				58.1	58.5		28			44.5				
SEBS 15WB	16	9	60	54.2	54.6	45	20	M4	4.5	38.8	–	–	–	13
SEBS 15WBY				73.3	73.7		35			57.9				

part number	standard rail length L mm										
SEBS 5WB	50	70	90	110	130	150	170	190			
SEBS 7WB	50	80	110	140	170	200	230	260	290	350	410
SEBS 9WB	50	80	110	140	170	200	230	260	290	350	410
SEBS 12WB	70	110	150	190	230	270	310	350	390	430	470
SEBS 15WB	70	110	150	190	230	270	310	350	390	430	470

Contact NB for rail length exceeds the maximum standard length listed in the dimensional tables.



N type rail tapped hole rail

※Refer to page 3 for description of accuracy

guide-rail dimensions							basic load rating		allowable static moment			mass		block size
H_1	C	B_1	d×G×h	S_3	N	P	dynamic C	static Co	M_P	M_Y	M_R	block	guide rail	
mm	mm	mm	mm		mm	mm	kN	kN	N・m	N・m	N・m	g	g/100mm	
4	10	－	3×5.5×3	M3	5	20	0.61	1.02	2.4	2.0	5.2	7	26	5WB
							0.88	1.47	4.9	4.1	7.4	10		5WBY
5.2	14	－	3.5×6×3.2	M4	10	30	1.59	2.57	9.1	7.7	18.3	20	51	7WB
							2.38	3.86	18.7	15.7	27.5	28		7WBY
7.5	18	－	3.5×6×4.5				2.31	3.85	17.0	14.3	35.6	37	96	9WB
							3.38	5.63	36.2	30.4	52.1	52		9WBY
8	24	－	4.5×8×4.5	M5	15	40	3.02	5.04	24.7	20.7	61.7	71	137	12WB
							4.54	7.56	58.2	48.8	92.6	106		12WBY
9.5	42	23					5.38	8.96	59.0	49.5	190.4	148	286	15WB
							8.07	13.45	131.4	110.3	285.7	216		15WBY

1kN≒102kgf　1N・m≒0.102kgf・m

470				
470	530			
550	630	710		
550	630	710	790	870

8

SEBS-B/SEBS-BY Type
SEBS-BM/SEBS-BYM Type

part number structure

example SEBS 15B Y M UU 2 T1 - 589 P N / W2

SEBS:anticorrosion

size

block size

blank	standard
Y	long

return cap

blank	resin
M	stainless steal

seal

blank	without seal
UU	seals on both ends

number of blocks attached to one rail

pre-load symbol

T0	clearance
blank	standard
T1	light pre-load

total length of rail

accuracy grade

blank	high
P	precision

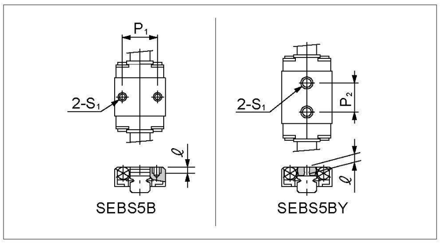
rail mounting hole

blank	counter-bore
N	tapped hole

symbol for number of rails

blank	single rail
W2	double rails
W3	triple rails

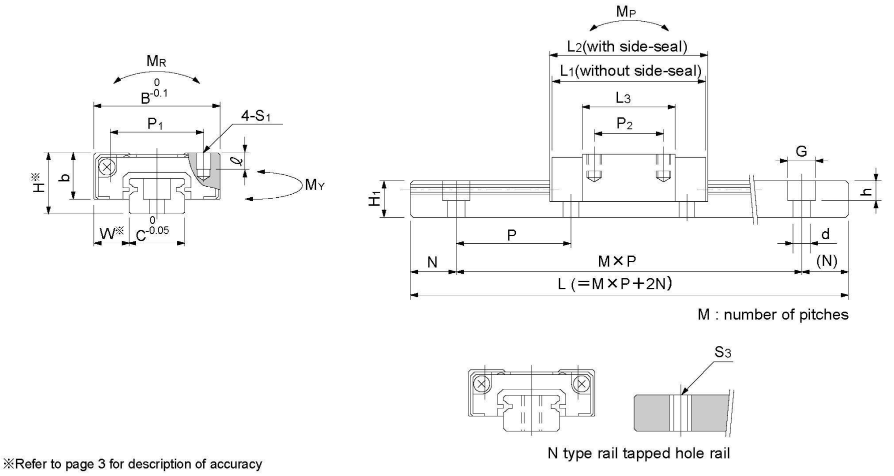
Note: The symbol for the number of rails does not mean the number of rails ordered.



part number		assembly dimensions	block dimensions									
resin return cap	stainless return cap	H mm	W mm	B mm	L_1 mm	L_2 mm	P_1 mm	P_2 mm	S_1	ℓ mm	L_3 mm	b mm
SEBS 5B	SEBS 5BM	6	3.5	12	16.3	16.7	8	–	M2	1.5	9.3	4.5
SEBS 5BY	SEBS 5BYM				19.3	19.7	–	7	M2.6	1.8	12.3	
SEBS 7B	SEBS 7BM	8	5	17	23	23	12	8	M2	2.5	12.8	6.5
SEBS 7BY	SEBS 7BYM				32.5	32.5		13			22.3	
SEBS 9B	SEBS 9BM	10	5.5	20	30.8	30.8	15	10	M3	3	19.6	7.8
SEBS 9BY	SEBS 9BYM				40.3	40.3		16			29.1	
SEBS 12B	SEBS 12BM	13	7.5	27	33.8	34.2	20	15		3.5	20.2	10
SEBS 12BY	SEBS 12BYM				45.7	46.1		20			32.1	
SEBS 15B	SEBS 15BM	16	8.5	32	41.6	42	25	20		4	26.6	12
SEBS 15BY	SEBS 15BYM				57.5	57.9		25			42.5	
SEBS 20B	SEBS 20BM	25	13	46	65.9	65.9	38	38	M4	6	44.7	17.5
SEBS 20BY	SEBS 20BYM				85.7	85.7					64.5	

part number	standard rail length L mm										
SEBS 5B	40	55	70	85	100	130	160				
SEBS 7B	40	55	70	85	100	130	160	190	220	250	280
SEBS 9B	55	75	95	115	135	155	175	195	235	275	315
SEBS 12B	70	95	120	145	170	195	220	245	270	295	320
SEBS 15B	70	110	150	190	230	270	310	350	390	430	470
SEBS 20B	220	280	340	400	460	520	580	640	760	880	1,000

Contact NB for rail length exceeds the maximum standard length listed in the dimensional tables.



※Refer to page 3 for description of accuracy

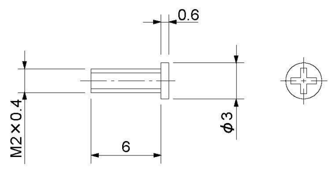
guide-rail dimensions						basic load rating		allowable static moment			mass			size
H_1	C	d×G×h	S_3	N	P	dynamic C	static Co	M_P	M_Y	M_R	block g resin return cap	block g stainless return cap	guide-rail	
mm	mm	mm		mm	mm	kN	kN	N・m	N・m	N・m			g/100mm	
4	5	2.4×3.5×0.8	M2.6	5	15	0.39	0.66	0.9	0.8	1.7	3	4	13	5B
						0.52	0.88	1.7	1.4	2.2	4	5		5BY
4.7	7	2.4×4.2×2.3	M3			1.10	1.70	3.5	3.0	6.2	9	12	21	7B
						1.93	2.98	11.0	9.3	10.8	15	18		7BY
5.5	9	3.5×6×3.5	M4	7.5	20	1.67	2.47	7.8	6.6	11.5	18	22	31	9B
						2.47	3.70	17.6	14.9	17.2	27	31		9BY
7.5	12	3.5×6×4.5		10	25	2.55	3.70	11.7	9.9	23.1	35	44	59	12B
						4.15	6.02	31.0	26.3	37.6	53	62		12BY
9.5	15		M5	15	40	4.26	6.36	26.9	22.8	49.2	64	77	97	15B
						6.92	10.3	71.1	60.2	80.1	98	110		15BY
15	20	6×9.5×8.5	M6	20	60	8.91	12.7	92.7	78.5	130	228	266	205	20B
						12.9	18.5	195	165	189	323	360		20BY

1kN≒102kgf　1N・m≒0.102kgf・m

310						
355	395	435	475			
345	370	395	420	445	470	495
510	550	590	630	670		

SEBS5 Custom mounting bolts

Custom mounting bolts are provided for SEBS5



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Phone:++31-20-453-4901 Fax:++31-20-453-6730
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Local Sales Representative:

No.5550
First Edition:Jul.31,2003

Appendix C6: Pulleys

The following pages were taken from the Sava Industries, Inc.® catalog (www.savacable.com)

CarlStahl® SAVA INDUSTRIES, INC.
P.O. Box 30 • 4 North Corporate Drive, Riverdale, New Jersey 07457-0030
973.835.0882 • Fax: 973.835.0877 • www.savacable.com
CABLE SOLUTIONS® ISO 9001 CERTIFIED

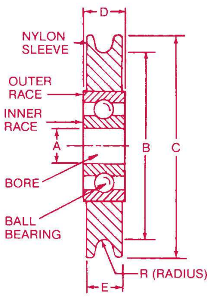
SMALL NYLON PULLEYS – BEARING MOUNTED (Cont.)

UP SERIES PULLEYS

SAVA's inexpensive UP series pulleys are used for moderate load and speed application not requiring the use of more precise ground bearings. The bulk of all applications falls into this category. The UP series pulleys are furnished with an open-type precision machined ball bearing, which is lightly lubricated.

UP2044, UP2050, and UP2063 are also available with open-type, ABEC1 precision ground bearings with ball retainers and are very free turning. If you wish to purchase a precision ground brearing for these pulleys, specify the pulley part followed by R2X1 Bearing; e.g., UP2044R2X1.

UP PULLEY



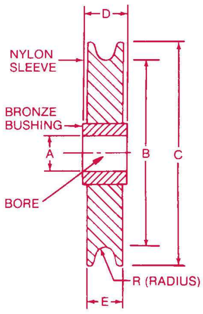
SAVA ITEM	REF. OLD PART NO.	A + .005 - .001	B ± .020	C ± .020	D ± .010	E ± .010	R REF.	CABLE SIZES TO	LOAD[2] (LBS)
UP2044	UP-243	.125	.437	.500	.156	.125	.025	3/64	10
UP2050	UP-250	.125	.500	.625	.156	.125	.015	1/32	10
UP2063	UP-263	.125	.625	.750	.156	.156	.025	3/64	10
UP2081[1]	UP-281	.125	.813	1.000	.171	.156	.025	3/64	35
UP3088	UP-387	.187	.885	1.070	.250	.219	.025	3/64	35
UP3106	UP-310	.187	1.063	1.250	.250	.219	.035	1/16	45
UP4088	UP-487	.250	.885	1.070	.250	.219	.025	3/64	35
UP4106	UP-410	.250	1.063	1.250	.250	.219	.035	1/16	45
UP4125	UP-413	.250	1.250	1.500	.312	.281	.050	3/32	80
UP4138	UP-414	.250	1.375	1.750	.312	.281	.065	1/8	80
UP6125	UP-613	.375	1.250	1.500	.312	.281	.050	3/32	70
UP6138	UP-614	.375	1.375	1.750	.312	.281	.065	1/8	70

NOTES: [1]UP2081 contains an ABEC1 precision ground shielded bearing with bore tolerance ± .0005.
[2]Dynamic Load Rating is given in lbs. at 500 RPM.

MP SERIES PULLEYS

This line of nylon pulleys offers a bushing of porous, sintered, self-lubricating bronze. The bushings are oil-impregnated at the factory. This vacuum impregnated oil, equivalent to SAE 30, supplements the pure bronze structure and forms a hydraulic cushion which absorbs unusual shocks and permits the bushing to carry heavier loads than SP or UP series pulleys. They are highly corrosion and wear resistant.

MP PULLEY



SAVA ITEM	REF. OLD PART NO.	A ± .002	B ± .020	C ± .020	D ± .010	E ± .010	R REF.	CABLE SIZES TO	STATIC LOAD LBS MAX.
MP2063	MP-263	.127	.625	.750	.187	.156	.025	3/64	20
MP3088	MP-387	.189	.885	1.070	.250	.219	.025	3/64	70
MP3106	MP-310	.189	1.063	1.250	.250	.219	.035	1/16	90
MP4088	MP-487	.252	.885	1.070	.250	.219	.025	3/64	70
MP4106	MP-410	.252	1.063	1.250	.250	.219	.035	1/16	90
MP4125	MP-413	.252	1.250	1.500	.313	.281	.050	3/32	160
MP4138	MP-414	.252	1.375	1.750	.313	.281	.065	1/8	180
MP6125	MP-613	.377	1.250	1.500	.313	.281	.050	3/32	160
MP6138	MP-614	.377	1.375	1.750	.313	.281	.065	1/8	180

STORAGE

SAVA's nylon pulleys with oil-impregnated sintered bronze bushings can be stored indefinitely in suitable containers using plastic bags, wax paper, metal, glass, etc. Woods, ordinary paper and cardboard are not suitable since they absorb oil from the bushings. Properly stored SAVA's oil-impregnated bushings retain their oil supply indefinitely.

Appendix D

Material Safety Data Sheets (MSDS)

Appendix D1: MSDS for Nickel Aerosol P/N SA-12N

The following pages were taken from the SAF-T-LOK INTERNATIONAL CORPORATION © catalog (www.saftlok.com)

Material Safety Data Sheet

NICKEL AEROSOL SA-12N

IDENTITY *(as used on label and list)* SAF-T-EZE NICKEL ANTI-SEIZE AEROSOL	
Manufacturer's name SAF-T-EZE DIV., STL COMPOUND CORPORATION 300 EISENHOWER LANE NORTH LOMBARD, ILLINOIS, USA 60148	Emergency Telephone Number Chemtrec 1-800-424-9300
	Telephone Number for Information 630-495-2001
Date Prepared NOVEMBER 01, 2007	

Section II—Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity, Common Name(s))		OSHA PEL	ACGIH TLV	Other Limits Recommended	% (optional)
Nickel	CAS# 7440-02-0		1mg/M3		
Butane	CAS# 106-97-8		800 ppm		
Propane	CAS# 74-98-6		1000ppm		

All components of this product are listed on the Toxic Substance Control Act (TSCA) inventory of chemical substances maintained by the U.S. Environmental Protection Agency.

Section III—Physical/Chemical Characteristics

Boiling Point	~100℉	Specific Gravity (H_20 = 1)	1.4
Vapor Pressure (mm Hg) PSIG @ 70℉	N/A	Melting Point	NIL
Vapor Density (AIR = 1)	~2.9	Evaporation Rate (Butyl Acetate = 1)	N/A
Solubility in Water	Negligible		
Appearance and Odor	Silver Grey aerosol with solvent odor		

Section IV—Fire and Explosion Hazard Data

Flash Point (Method Used)	N/A	Flammable Limits	LEL N/A / UEL N/A

Extinguishing Media	Foam CO_2, Dry Chemicals
Special Fire Fighting Procedures	Water maybe ineffective but may be used to keep fire exposed containers cool until fire is out. Dense smoke may be generated while burning. Use NIOSH approved respirator and protective clothing.
Unusual Fire and Explosion Hazards	Aerosol cans may explode if heated over 130℉

Decomposition vapors may be harmful. Aerosols may be kept at temperature below 130℉ to prevent any potential explosion hazard. Hot fire could release nickel, a suspected carcinogen.

Section V—Reactivity Data

Stability	Unstable		Conditions to Avoid High Temperatures.
	Stable	X	
Incompatibility (Materials to Avoid)	Strong Oxidizing Agents		
Hazardous Decomposition or Byproducts	CO, CO_2		
Hazardous Polymerization	May Occur		Conditions to Avoid
	Will not Occur	X	

Section VI—Health Hazard Data			
Route(s) of Entry:	Inhalation? N/A	Skin? Contact	Ingestion? Contact
Health Hazards (Acute and Chronic)	The information shown refers generally to a component of the product but as required by OSHA 1910.1200 the hazards of any ingredient must be extended to the product as a whole unless testing of the product has been performed.		
Carcinogenicity: Suspected from Nickel	NTP? NO	IARC Monographs? NO	OSHA Regulated NO
Signs and Symptoms of Exposure	SKIN: Prolonged or repeated contact may lead to skin irritation in some individuals. EYES: Redness and irritation. INHALATION: None known. INGESTION: Nausea, abdominal cramps.		
Medical Conditions Generally aggravated by Exposure	May aggravate pre-existing skin sensitive in individuals, otherwise, none known.		
Emergency and First Aid Procedures	EYES: Flush thoroughly with water, get medical attention. SKIN: Wash with soap and water. INGESTION: No ill effects expected for small amount, give 2 glasses of water and induce vomiting.		

Section VII—Precautions for Safe Handling and Use	
Steps to be Taken in Case Material is Released or Spilled	Remove any source of ignition. Scoop up as much as possible, cover the remainder with an oil absorbent such as sand, earth or sweeping compound.
Waste Disposal Method	Dispose of in accordance with federal, State and Local Regulations.
Precautions to be Taken in Handling and Storing	Store away from sparks, open flames or excessive heat. Keep container closed when not in use.
Other Precautions	Use good normal industrial hygienic practices. Avoid skin contact.

Section VIII—Control Measures			
Respiratory Protection (Specify Type)	Self contained breathing apparatus if above TLV limit.		
Ventilation:	Local Exhaust: Preferred	Special	N/A
	Mechanical (General): Acceptable	Other	N/A
Protective Gloves	Yes, oil resistant	Eye Protection	Safety glasses or chemical goggles
Other Protective Clothing or Equipment	Safety shower and eye wash		
Work/Hygienic Practices	Normal good industrial hygiene, wash hands before meals and at end of shift.		

The information on this data sheet represents our current data and best opinion as to the proper use in handling of this product under normal conditions. Any use of the product which is not in conformance with this data sheet or which involves using the product in combination with any other product or any other process is the responsibility of the user.

Appendix D2: MSDS for way lube oil #68, RAMCO® P/N 1011

The following pages were taken from the Ramco Specialty Products, Inc. © Catalog (www.ramcospec.com)

RAMCO SPECIALTY PRODUCTS INC	**WAY LUBE OIL #68** **MATERIAL SAFETY DATA SHEET** *Complies with OSHA Hazard Communication Standard (29CFR 1910.1200)*

Manufactured For: RAMCO SPECIALTY PRODUCTS, Inc. ♦ 5956 State Road ♦ Bakersfield, CA 93308-3022
Phone: (800) 334-7071 ♦ Fax: (714) 375-1225 ♦ Website: www.ramcospec.com

SECTION I – PRODUCT IDENTIFICATION

PRODUCT NAME	**WAY LUBE OIL #68 (Bulk)**	PROPER SHIPPING NAME	**OIL N.O.S.**
PRODUCT NUMBER	**1011**	DATE PREPARED	**02/19/2004**
PRODUCT DESCRIPTION	**Machine, Stamping Oil**	PREPARED BY	**WARREN SQUYRES**
Information Phone	**(800) 334-7071**	24-Hour Emergency Phone No.	**(800) 255-3924**

NFPA – HMIS CODES

Health	**1**	Flammability	**1**	Corrosive	**0**	Reactivity	**0**	Personal Protection	**C**

SECTION II – MATERIAL IDENTIFICATION AND INFORMATION

Description	CAS Number	SARA III LIST/CARCINOGEN	OSHA PEL/TLV	OSHA STEL	ACGIH TLV	ACGIH STEL
May contain one or more of the following			5mg/m3 (Oil Mist)		5mg/m3 (Oil Mist)	
lubricating base stocks:	64742-54-7	NO/NO				
	64742-70-7	NO/NO				
	64742-65-0	NO/NO				
	64742-57-0	NO/NO				
Hydrogen Sulfide	7783-08-4	NO/NO	10ppm (TWA)	15ppm	10ppm (TWA)	15ppm

Please note that the chemical identity of some or all of the above hazardous ingredients is confidential information and may be withheld as permitted by 29CFR 1910.1200 and various State Right to Know Laws.

SECTION III – PHYSICAL/CHEMICAL CHARACTERISTICS

Initial Boiling Point, °F	N/E	**Evaporation Rate (n-Bu-Ac=1.0)**	N/E
Vapor Pressure for Product	Negligible at Ambient	**Melting Point, °F**	N/A
Vapor Density for Product (Air = 1.0)	Heavier than Air	**Molecular Weight, Avg.**	N/E
Specific Gravity (H2O=1 @ 15.8°C)	0.87 – 0.89	**Viscosity, Typical (cp)**	N/E
VOC (Grams/Liter @ 25°C)	N/E	**Appearance and Color**	Clear Brown Liquid
Volatiles, % by Volume @ 100°C	Negligible	**Odor**	Petroleum Oil
Total VOC %	N/E	**Water Solubility (Wt %)**	Negligible

The above data are appropriate or typical values and should not be used for precise design purposes.

SECTION IV – FIRE AND EXPLOSION HAZARD DATA

Flash Point (ASTM D92) C.O.C.	300°F (Min.)
Auto Ignition Temperatures	N/E
Flammability Limits in Air	
Lower Explosive Limit Estimated	N/E
Upper Explosive Limit Estimated	N/E
Extinguishing Media	Carbon Dioxide, Dry Chemical, Foam, or water-fog. Water spray can be used to cool and protect containers exposed to heat and flame.
Unusual Fire and Explosion Hazards	Toxic fumes, gases or vapors may evolve on burning. Vapors may be heavier than air and may travel along the ground to a distant ignition source and flash back if exposed to ignition. Exposing product to intense heat could cause drums to rupture.
Special Fire Fighting Procedures	Wear positive pressure self-contained breathing apparatus. Do not enter confined fire-space without full bunker gear (helmet with face shield, bunker coats, gloves and rubber boots). Move container from fire area if you can do so without risk. Apply cooling water to sides of containers that are exposed to flames until well after fire is out.

RAMCO SPECIALTY PRODUCTS INC	**WAY LUBE OIL #68**

SECTION V – HEALTH HAZARD DATA AND EMERGENCY FIRST AID PROCEDURES

ENTRY ROUTES	ADVERSE/CHRONIC EFFECTS	FIRST AID PROCEDURES
EYES	Not expected to cause eye irritation. Based on data from components or similar materials.	Immediately flush eyes with large amounts of water for at least 15 minutes while holding eyelids open. Get prompt medical attention if irritation occurs.
INGESTION	Product has a low degree of acute oral, but minute amounts aspirated into the lungs during ingestion or vomiting may cause mild to severe pulmonary injury and possible death. Based on data from components or similar materials.	DO NOT INDUCE VOMITING. Keep warm and quiet. Get prompt medical attention.
INHALATION	Not expected to be an inhalation hazard at ambient temperatures. Based on data from components or similar materials. Inhalation of high concentrations of hydrogen sulfide vapor may cause loss of consciousness and death. Inhalation of lower concentrations may cause headache, dizziness and nausea.	If adverse effects are observed, remove to fresh air. If symptoms persist, seek medical attention. If victim is not breathing, immediately begin artificial respiration. Seek immediate medical attention.
SKIN	May cause slight skin irritation. Based on data from components or similar materials.	In case of skin contact, remove contaminated clothing and wash skin with soap and water. Get medical attention if irritation persists or develops. Launder or dry-clean clothing before reuse.

VARIABLE AMONG INDIVIDUALS	Health studies have shown that many petroleum hydrocarbons and synthetic lubricants pose potential human health risks which may vary from person to person. As a precaution, exposure to liquids, vapors, mists or fumes should be minimized.
ADDITIONAL INFORMATION	Material may liberate hydrogen sulfide gas. The ACGIH TLV-TWA for hydrogen sulfide is 10ppm. The ACGIH 15 MINUTE STEL is 15ppm. OSHA acceptable ceiling concentration for hydrogen sulfide is 20ppm. A 10 minute maximum peak of 50ppm is permitted once, only if no other measurable exposure occurs.

NOTE TO PHYSICIAN: Hydrogen Sulfide ion is strongly bound to methemoglobin in a manner similar to cyanide. A dose of sodium nitrate would produce methemoglobin in the blood which would then partially inactivate this poison.

SECTION VI – REACTIVITY DATA

STABILITY	Stable under normal conditions of storage and handling.
HAZARDOUS POLYMERIZATION	Will not occur – No conditions known.
INCOMPATIBILITY	Strong Oxidizing Agents and acids, Halogens and Halogenated Compounds.
HAZARDOUS DECOMPOSITION	A complex mixture of airborne solid, liquid, particulates and gases will evolve when this material undergoes pyrolysis or combustion. Fumes, smoke, carbon monoxide, aldehydes and other products of incomplete combustion. Under normal combustion conditions, oxides of the following elements will be formed: sulfur. Hydrogen sulfide may also be released. Hydrogen sulfide is a toxic and flammable gas.

SECTION VII – PRECAUTIONS FOR SAFE HANDLING AND USE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED – Remove all sources of ignition. Recover free product. Add sand, earth or other suitable absorbent to spill area. Minimize skin contact. Keep product out of sewers and watercourses by diking or impounding. Advise authorities if product has entered or may enter sewers, watercourses, or extensive land areas. Assure conformity with applicable governmental regulations.

WASTE DISPOSAL	Waste disposal should be in compliance with all Federal, State, and Local laws. Determine at time of disposal whether the product meets RCRA criteria for a hazardous waste.
HANDLING & STORAGE	Keep away from potential sources of ignition. Liberates hydrogen sulfide gas. Open container carefully and only in use in adequately ventilated areas or use appropriate respiratory protection. Use product with caution around heat, sparks, pilot lights, static electricity and open flame. Product can burn upon heating to temperatures at or above flashpoint. Keep containers closed when not in use. Do not store near heat, sparks, flame or strong oxidants.
OTHER PRECAUTIONS	KEEP OUT OF REACH OF CHILDREN. Read and follow label directions. For Industrial/Institutional use only.
"EMPTY" CONTAINERS	"EMPTY" containers retain residue (liquid and/or vapor) and can be dangerous. Do not pressurize, cut, weld, braze, solder, drill, grind, or expose such containers to heat, flame, sparks, static electricity, or other sources of ignition; they may explode and cause injury or death. Do not attempt to clean since residue is difficult to remove. "Empty" drums should be completely drained, properly bunged and promptly returned to a drum reconditioner. All containers should be disposed of in an environmentally safe manner and in accordance with governmental regulations.

SECTION VIII – CONTROL MEASURES

RESPIRATORY PROTECTION	Hydrogen sulfide causes olfactory fatigue and thus has poor warning properties. NIOSH recommends the use of supplied air for exposures up to 100ppm and self-contained breathing apparatus for exposures greater than 100ppm. When the exposure limit for hydrogen sulfide may be exceeded these types of respiratory protection should be available for use.
VENTILATION	Use local exhaust to capture vapor, mists or fumes, if necessary. Provide ventilation sufficient to prevent exceeding recommended exposure limit or build-up of explosive concentrations, or vapors in air. No smoking, flame or other ignition sources.
PROTECTIVE GLOVES	Use chemical resistant gloves to avoid prolonged or repeated skin contact.
EYE PROTECTION	Use splash goggles or face shield when eye contact may occur.
OTHER PROTECTIVE CLOTHING/EQUIPMENT	Use chemical resistant apron or other impervious clothing, if needed, to avoid contamination of regular clothing. Long sleeve shirt is recommended.
WORK HYGIENIC PRACTICES	Minimize breathing vapor, mists or fumes. Avoid prolonged or repeated contact with skin. Employees must practice good personal hygiene; washing exposed areas of skin several times daily and before eating, drinking or smoking. Launder contaminated clothing before reuse. Remove contaminated shoes and thoroughly clean before reuse; discard if oil-soaked.

SECTION IX – TRANSPORTATION DATA

PROPER SHIPPING NAME	**OIL N.O.S.**
DOT ID NUMBER	**N/A**
DOT HAZARD CLASS	**NOT REGULATED**

MSDS 2004

Appendix D3: MSDS for HIGH THERMAL K HEAT TRANSFER EPOXY RESIN, P/N 50-3100

The following pages were taken from the Epoxies, Etc… © Catalog (www.epoxies.com)

Material Safety Data Sheet
acc. to ISO/DIS 11014

Printing date 04/14/2006 — *Reviewed on 03/29/2006*

1 Identification of substance

· ***Product details***

· ***Trade name: 50-3100R***

· ***Article number:*** *Epoxy Resin Formulation*

· ***Manufacturer/Supplier:***
Epoxies, Etc.
21 Starline Way
Cranston, RI 02921
USA

· ***Information department:*** *Product safety department.*
· ***Emergency information:*** *800-255-3924*

2 Composition/Data on components

· ***Chemical characterization***
· ***Description:*** *Mixture of the substances listed below with nonhazardous additions.*

· ***Dangerous components:***		
25068-38-6	*reaction product: bisphenol-A-(epichlorhydrin) epoxy resin (number average molecular weight ≤ 700)*	*25-50%*

3 Hazards identification

· ***Hazard description:***

Irritant
Dangerous for the environment

· ***Information pertaining to particular dangers for man and environment:***
Irritating to eyes and skin.
May cause sensitisation by skin contact.
Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
Only for trade users / technical specialists
Keep out of the reach of children.
· ***Classification system:***
The classification was made according to the latest editions of international substances lists, and expanded upon from company and literature data.
· ***NFPA ratings (scale 0 - 4)***

Health = 1
Fire = 1
Reactivity = 0

· ***HMIS-ratings (scale 0 - 4)***

Health = 1
Fire = 1
Reactivity = 0

USA

(Contd. on page 2)

Material Safety Data Sheet
acc. to ISO/DIS 11014

Printing date 04/14/2006 *Reviewed on 03/29/2006*

Trade name: 50-3100R

(Contd. of page 1)

4 First aid measures

· ***After inhalation:***
Supply fresh air. If required, provide artificial respiration. Keep patient warm. Consult doctor if symptoms persist.
In case of unconsciousness place patient stably in side position for transportation.
· ***After skin contact:***
Immediately wash with water and soap and rinse thoroughly.
If skin irritation continues, consult a doctor.
· ***After eye contact:***
Rinse opened eye for several minutes under running water. If symptoms persist, consult a doctor.
· ***After swallowing:***
If symptoms persist consult doctor.
A person vomiting while lying on their back should be turned onto their side.
DO NOT attempt to give anything by mouth to an unconscious person.

5 Fire fighting measures

· ***Suitable extinguishing agents:***
CO2, extinguishing powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
Use fire fighting measures that suit the environment.
· ***Protective equipment:***
Wear self-contained respiatory protective device.
Wear fully protective suit.
Do not inhale explosion gases or combustion gases.

6 Accidental release measures

· ***Person-related safety precautions:***
Wear protective clothing.
Keep people at a distance and stay upwind.
· ***Measures for environmental protection:***
Do not allow product to reach sewage system or any water course.
Inform respective authorities in case of seepage into water course or sewage system.
Do not allow to enter sewers/ surface or ground water.
· ***Measures for cleaning/collecting:***
Dispose contaminated material as waste according to item 13.
Send for recovery or disposal in suitable receptacles.
Absorb with liquid-binding material (sand, diatomite, acid binders, universal binders, sawdust).
Ensure adequate ventilation.

7 Handling and storage

· ***Handling:***
· ***Information for safe handling:***
Store in cool, dry place in tightly closed receptacles.
Ensure good ventilation/exhaustion at the workplace.
Prevent formation of aerosols.
Store at ambient temperature 25 C.
· ***Information about protection against explosions and fires:*** *No special measures required.*

· ***Storage:***
· ***Requirements to be met by storerooms and receptacles:***
Store only in the original receptacle.

(Contd. on page 3)

Material Safety Data Sheet

acc. to ISO/DIS 11014

Printing date 04/14/2006 *Reviewed on 03/29/2006*

Trade name: 50-3100R

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Stoor indoors.

· ***Information about storage in one common storage facility:*** *Not required.*

· ***Further information about storage conditions:*** *Keep receptacle tightly sealed.*

8 Exposure controls and personal protection

· ***Additional information about design of technical systems:*** *No further data; see item 7.*

· ***Components with limit values that require monitoring at the workplace:***
The product does not contain any relevant quantities of materials with critical values that have to be monitored at the workplace.

· ***Additional information:*** *The lists that were valid during the creation were used as basis.*

· ***Personal protective equipment:***

· ***General protective and hygienic measures:***
Keep away from foodstuffs, beverages and feed.
Immediately remove all soiled and contaminated clothing.
Wash hands before breaks and at the end of work.
Avoid contact with the eyes and skin.

· ***Breathing equipment:***
In case of brief exposure or low pollution use respiratory filter device. In case of intensive or longer exposure use respiratory protective device that is independent of circulating air.

· ***Protection of hands:***

Protective gloves

The glove material has to be impermeable and resistant to the product/ the substance/ the preparation.
Due to missing tests no recommendation to the glove material can be given for the product/ the preparation/ the chemical mixture.
Selection of the glove material on consideration of the penetration times, rates of diffusion and the degradation

· ***Material of gloves***
The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer. As the product is a preparation of several substances, the resistance of the glove material can not be calculated in advance and has therefore to be checked prior to the application.

· ***Penetration time of glove material***
The exact break trough time has to be found out by the manufacturer of the protective gloves and has to be observed.

· ***Eye protection:***

Tightly sealed goggles

9 Physical and chemical properties

· ***General Information***

Form:	*Liquid*
Color:	*According to product specification*
Odor:	*Characteristic*

(Contd. on page 4)

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Trade name: 50-3100R

(Contd. of page 3)

· **Change in condition**	
Melting point/Melting range:	Undetermined.
Boiling point/Boiling range:	> 260°C (> 500°F)
· **Flash point:**	149°C (300°F)
· **Auto igniting:**	Product is not selfigniting.
· **Danger of explosion:**	Product does not present an explosion hazard.
· **Density:**	Not determined.
· **Solubility in / Miscibility with Water:**	Not miscible or difficult to mix.
· **Solvent content:**	
Organic solvents:	0.0 %
· **Solids content:**	99.8 %

10 Stability and reactivity

· ***Thermal decomposition / conditions to be avoided:***
No decomposition if used and stored according to specifications.
Avoid elevated temperatures.
· ***Materials to be avoided:*** *Strong acids, strong bases, strong oxidizers, amines, and mercaptans.*
· ***Dangerous reactions***
Reacts with amines.
Reacts with catalysts, oxidizing agents and strong alkali.
Hazardous polymerization may occur if mixed with amines in large masses and/or with heat.
· ***Dangerous products of decomposition:***
Carbon monoxide and carbon dioxide
Unknown hydrocarbons.

11 Toxicological information

· ***Acute toxicity:***
· ***Primary irritant effect:***
· ***on the skin:*** *Irritant to skin and mucous membranes.*
· ***on the eye:*** *Irritating effect.*
· ***Sensitization:*** *Sensitization possible through skin contact.*
· ***Additional toxicological information:***
The product shows the following dangers according to internally approved calculation methods for preparations:
Irritant

12 Ecological information

· ***Ecotoxical effects:***
· ***Remark:*** *Toxic for fish*
· ***General notes:***
Water hazard class 2 (Self-assessment): hazardous for water
Do not allow product to reach ground water, water course or sewage system.
Danger to drinking water if even small quantities leak into the ground.
Also poisonous for fish and plankton in water bodies.

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acc. to ISO/DIS 11014

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Trade name: 50-3100R

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Toxic for aquatic organisms

13 Disposal considerations

· **Product:**
· **Recommendation:**
Must not be disposed of together with household garbage. Do not allow product to reach sewage system.

· **Uncleaned packagings:**
· **Recommendation:**
Disposal must be made according to official regulations.
Dispose of in accordance to all local, state, and/or national regislation.

14 Transport information

· **DOT regulations:**
· **Hazard class:** -
· **Remarks:** *Not regulated.*

· **Maritime transport IMDG:**
· **IMDG Class:** -
· **Marine pollutant:** *No*
· **Remarks:** *Not regulated.*

· **Air transport ICAO-TI and IATA-DGR:**
· **ICAO/IATA Class:** -
· **Remarks:** *Not regulated*

15 Regulations

· **Sara**

· **Section 355 (extremely hazardous substances):**
None of the ingredient is listed.

· **Section 313 (Specific toxic chemical listings):**

1344-28-1	aluminium oxide

· **TSCA (Toxic Substances Control Act):**

1344-28-1	aluminium oxide
25068-38-6	reaction product: bisphenol-A-(epichlorhydrin) epoxy resin (number average molecular weight ≤ 700)
7631-86-9	silicon dioxide, chemically prepared
1333-86-4	Carbon black

· **Proposition 65**

· **Chemicals known to cause cancer:**

1333-86-4	Carbon black

· **Chemicals known to cause reproductive toxicity for females:**
None of the ingredients is listed.

· **Chemicals known to cause reproductive toxicity for males:**
None of the ingredients is listed.

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Material Safety Data Sheet
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Printing date 04/14/2006 *Reviewed on 03/29/2006*

Trade name: 50-3100R

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· ***Chemicals known to cause developmental toxicity:***
None of the ingredients is listed.

· ***Cancerogenity categories***

· ***EPA (Environmental Protection Agency)***
None of the ingredients is listed.

· ***IARC (International Agency for Research on Cancer)***

7631-86-9	silicon dioxide, chemically prepared	3
1333-86-4	Carbon black	2B

· ***NTP (National Toxicology Program)***
None of the ingredients is listed.

· ***TLV (Threshold Limit Value established by ACGIH)***

1344-28-1	aluminium oxide	A4
1333-86-4	Carbon black	A4

· ***NIOSH-Ca (National Institute for Occupational Safety and Health)***

1333-86-4	Carbon black

· ***OSHA-Ca (Occupational Safety & Health Administration)***
None of the ingredients is listed.

· ***Product related hazard informations:***
The product has been classified and marked in accordance with directives on hazardous materials.

· ***Hazard symbols:***
Irritant
Dangerous for the environment

· ***Hazard-determining components of labelling:***
reaction product: bisphenol-A-(epichlorhydrin) epoxy resin (number average molecular weight $\leq$ 700)

· ***Risk phrases:***
Irritating to eyes and skin.
May cause sensitisation by skin contact.
Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

· ***Safety phrases:***
Keep out of the reach of children.
Avoid contact with skin and eyes.
Do not empty into drains, dispose of this material and its container at hazardous or special waste collection point.
Wear suitable gloves and eye/face protection.
After contact with skin, wash immediately with plenty of soap and water.

· ***Special labeling of certain preparations:***
Only for trade users / technical specialists
Keep out of the reach of children.

16 Other information

This information is based on our present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship. The information given and the recomendations made herein apply to our product alone and are not combined with other product(s). Such are based on our research and on data from other reliable sources and are believed to be accurate. No guarantee of accuracy is made. It is the user's responsibility before using any product to verify this data under their own operating conditions and to determine whether the product is suitable for their purposes.

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Trade name: 50-3100R

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· ***Department issuing MSDS:*** *Product safety department.*
· ***Contact:*** *Paul C. Harrington*

USA

Appendix D4: MSDS for CATALYST 190

The following pages were taken from the **Epoxies, Etc... © Catalog (www.epoxies.com)**

Material Safety Data Sheet
acc. to ISO/DIS 11014

Printing date 04/19/2007 *Reviewed on 05/10/2006*

1 Identification of substance

· ***Product details***

· ***Trade name:*** ***CAT.190***

· ***Article number:*** *Polyamine Formulation*

· ***Manufacturer/Supplier:***
Epoxies, Etc.
21 Starline Way
Cranston, RI 02921
USA

· ***Information department:*** *Product safety department.*
· ***Emergency information:*** *800-255-3924*

2 Composition/Data on components

· ***Chemical characterization:***
· ***CAS No. Description***
112-57-2 tetraethylenepentamine
· ***Identification number(s)***
· ***EINECS Number:*** *203-986-2*
· ***EU Number:*** *612-060-00-0*

· ***Chemical characterization***
· ***Additional information:*** *Chemical Family: Aliphatic Amine Mixture*

3 Hazards identification

· ***Hazard description:***

Corrosive
Dangerous for the environment

· ***Information pertaining to particular dangers for man and environment:***
The product has to be labelled due to the calculation procedure of international guidelines.
Harmful in contact with skin and if swallowed.
Causes burns.
Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
Irritating to respiratory system and skin.
May cause sensitisation by inhalation and skin contact.
Risk of serious damage to eyes.
Only for trade users / technical specialists
Keep out of the reach of children.
· ***Classification system:***
· ***NFPA ratings (scale 0 - 4)***

Health = 3
Fire = 1
Reactivity = 0

· ***HMIS-ratings (scale 0 - 4)***

Health = 3
Fire = 1
Reactivity = 0

(Contd. on page 2)

USA

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Printing date 04/19/2007 Reviewed on 05/10/2006

Trade name: CAT.190

(Contd. of page 1)

· ***Additional information:***
Additional Health Hazards:Corrosive to the eyes, skin, and respiratory tract. May be toxic if absorbed through skin.

Inhalation: May cause severe eye, skin, and respiratory tract burns. May cause nose, throat, and lung irritation. Inhalation of vapors and/or aerosols in high concentration may cause irritation of the respiratory system.

Eye Contact: Causes eye burns. May cause blindness. Severe eye irritation.

Skin contact: Causes skin burns.

Ingestion: Causes Severe burns of the mouth and throat, as well as a danger of perforation of the oesophagus and the stomach.

4 First aid measures

· ***General information:***
Immediately remove any clothing soiled by the product.
Symptoms of poisoning may even occur after several hours; therefore medical observation for at least 48 hours after the accident.
· ***After inhalation:***
Supply fresh air. If required, provide artificial respiration. Keep patient warm. Consult doctor if symptoms persist.
In case of unconsciousness place patient stably in side position for transportation.
· ***After skin contact:***
Immediately remove contaminated clothing, and any extraneous chemical, if possible to do so without delay. Initiate and maintain gentle and continuous irrigation with water until the patient receives medical care. If medical care is not promptly available, continue to iirigate (use soap if available) for one hour. Cover the wound with sterile dressing. Take off contaminated clothing and shoes immediately. Do not reuse clothing until thoroughly cleaned.

NOTE TO PHYSICIANS: Application of corticosteroid cream has been effective in treating skin irritation.
· ***After eye contact:***
Hold eyelids apart, initiate and maintain gentle and continuous irrigation of the eye with water until the patient receives medical care. If medical care is not promptly available, conitinue to irrigate for one hour. Rinse immediately with plenty of water also under the eyelids for atleast 20 minutes.
· ***After swallowing:***
A person vomiting while lying on their back should be turned onto their side.
Never give anything by mouth to an unconsciuos person. Do not induce vomiting. Give one glass of water unless victim is drowsy, convulsing, or unconscious. Seek medical attention immediately.

5 Fire fighting measures

· ***Suitable extinguishing agents:***
CO2, extinguishing powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
Use fire fighting measures that suit the environment.
· ***For safety reasons unsuitable extinguishing agents:***
Do not use water in a jet. Product will float. Water or fog may cause frothing which can be violent, especially if sprayed into containers of hot or burning liquid.

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Trade name: CAT.190

(Contd. of page 2)

· ***Special hazards caused by the material, its products of combustion or resulting gases:***
Material will not burn unless preheated. Delayed lung damage (pulmonary edema) can be experienced after exposure to combustion products, sometimes hours after the exposure. May generate ammonia gas, toxic nitrogen oxide gasess and other potentially hazardous nitrogen-containing compounds may be released upon combustion.

Use of water to fight fire may result in the formation of very toxic aqueous solutions. Incomplete combustion may form carbon monoxide. Downwind personnel must be evacuated. Burning produces obnoxious and toxic fumes.

Cool fire exposed containers with water.
· ***Protective equipment:***
Do not enter confined fire space without full bunker gear (helmet with face shield, bunker coats, gloves, and rubber boots) including a positive pressure NIOSH approved self-contained breathing apparatus.

6 Accidental release measures

· ***Person-related safety precautions:***
Corrosive. Use self-contained breathing apparatus and chemically protective clothing. Evacuate personnel to safe areas. Use cautious judgement when cleaning up large spills. Shut off leaks, if possible without personal risk.
· ***Measures for environmental protection:***
Do not allow product to reach sewage system or any water course.
Inform respective authorities in case of seepage into water course or sewage system.
Do not allow to enter sewers/ surface or ground water.
· ***Measures for cleaning/collecting:***
Absorb with liquid-binding material (sand, diatomite, acid binders, universal binders, sawdust).
Use neutralizing agent.
Dispose contaminated material as waste according to item 13.
Ensure adequate ventilation.

7 Handling and storage

· ***Handling:***
· ***Information for safe handling:***
DANGER: Corrosive

Avoid contact with skin and eyes. Emergency Showers and eye wash stations should be readily accessible. Use only in well-ventilated areas. Avoid breathing vapors and/or aerosols.

Heating this product above 300 Deg. F in the presence of air may cause slow oxidative decomposition; above 500 Deg. F, polymerization may occur. Some epoxy resins can produce exothermic reactions which in large masses can cause runaway polymerization. Fumes and vapors from these thermal and chemical decomposition may be extremely toxic. Use either an atmosphere-supplying respirator or an air-purifying respirator for organic vapors.
· ***Information about protection against explosions and fires:*** *No special measures required.*

· ***Storage:***
· ***Requirements to be met by storerooms and receptacles:***
Store in a cool, dry place with adequate ventilation. Keep away from open flames and high temperatures.
· ***Information about storage in one common storage facility:***
Do not store together with oxidizing and acidic materials.
· ***Further information about storage conditions:*** *Keep receptacle tightly sealed.*

USA

(Contd. on page 4)

Material Safety Data Sheet
acc. to ISO/DIS 11014

Printing date 04/19/2007 *Reviewed on 05/10/2006*

Trade name: CAT.190

(Contd. of page 3)

8 Exposure controls and personal protection

· **Additional information about design of technical systems:** No further data; see item 7.

· Components with limit values that require monitoring at the workplace:	
112-57-2 tetraethylenepentamine	
WEEL	5 mg/m³

· **Additional information:** The lists that were valid during the creation were used as basis.

· **Personal protective equipment:**
· **General protective and hygienic measures:**
Keep away from foodstuffs, beverages and feed.
Immediately remove all soiled and contaminated clothing.
Wash hands before breaks and at the end of work.
Avoid contact with the eyes and skin.
· **Breathing equipment:**
In case of brief exposure or low pollution use respiratory filter device. In case of intensive or longer exposure use respiratory protective device that is independent of circulating air.
· **Protection of hands:**


Protective gloves

The glove material has to be impermeable and resistant to the product/ the substance/ the preparation.
Due to missing tests no recommendation to the glove material can be given for the product/ the preparation/ the chemical mixture.
Selection of the glove material on consideration of the penetration times, rates of diffusion and the degradation
· **Material of gloves**
The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer.
· **Penetration time of glove material**
The exact break trough time has to be found out by the manufacturer of the protective gloves and has to be observed.
· **Eye protection:**


Tightly sealed goggles

Full face shields with tightly sealed goggles underneath. Contact lenses should not be worn.
· **Body protection:** Impervious protective clothing

9 Physical and chemical properties

· General Information	
Form:	Liquid
Color:	According to product specification
Odor:	Amine-like
· **Change in condition**	
Melting point/Melting range:	Undetermined.
Boiling point/Boiling range:	333°C (631°F)
· **Flash point:**	163°C (325°F)

(Contd. on page 5)

Material Safety Data Sheet
acc. to ISO/DIS 11014

Printing date 04/19/2007 *Reviewed on 05/10/2006*

Trade name: CAT.190

(Contd. of page 4)

· **Danger of explosion:**	Product does not present an explosion hazard.
· **Vapor pressure at 20°C (68°F):**	0.01 hPa (0 mm Hg)
· **Density at 20°C (68°F):**	1 g/cm³
· **Solubility in / Miscibility with** **Water:** **Organic solvents:**	Not miscible or difficult to mix. 0.0 %
· **Solids content:**	100.0 %

10 Stability and reactivity

· **Thermal decomposition / conditions to be avoided:** No decomposition if used according to specifications.
· **Materials to be avoided:**
Sodium hypochlorite, lewis or mineral acids, Organic bases such as primary and secondary aliphatic amines, ketones, aldehydes, and oxidizing agents. Reaction with peroxides may result in violent decomposition of peroxide possibly creating an explosion. A reaction accompanied by large heat release occurs when the product is mixed with acids.
· **Dangerous reactions** Hazardous polymerization may occur with epoxy resins in large masses.
· **Dangerous products of decomposition:**
Nitrogen oxides, ammonia, carbon monoxide and unidentified organic compounds (some containing nitrogen) may be formed during thermal or oxidative decomposition or combustion. Nitrogen oxide can react with water vapors to form corrosive nitric acid.

11 Toxicological information

· **Acute toxicity:**

· **LD/LC50 values that are relevant for classification:**		
112-57-2 tetraethylenepentamine		
Dermal	LD50	660 mg/kg (rabbit)

· **Primary irritant effect:**
· **on the skin:** Strong caustic effect on skin and mucous membranes.
· **on the eye:** Strong irritant with the danger of severe eye injury.
· **Sensitization:** Sensitization possible through skin contact.
· **Additional toxicological information:**
Swallowing will lead to a strong caustic effect on mouth and throat and to the danger of perforation of esophagus and stomach.

12 Ecological information

· **Ecotoxical effects:**
· **Remark:** Toxic for fish
· **General notes:**
Water hazard class 2 (Assessment by list): hazardous for water
Do not allow product to reach ground water, water course or sewage system.
Must not reach bodies of water or drainage ditch undiluted or unneutralized.
Danger to drinking water if even small quantities leak into the ground.
Also poisonous for fish and plankton in water bodies.

(Contd. on page 6)

Material Safety Data Sheet
acc. to ISO/DIS 11014

Printing date 04/19/2007 — *Reviewed on 05/10/2006*

Trade name: CAT.190

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Toxic for aquatic organisms

13 Disposal considerations

· ***Product:***
· ***Recommendation:***
Must not be disposed of together with household garbage. Do not allow product to reach sewage system.

· ***Uncleaned packagings:***
· ***Recommendation:***
Disposal must be made according to official regulations.
Dispose of in accordance to all local, state, and/or national regislation.

14 Transport information

· ***DOT regulations:***

· ***Hazard class:***	*8*
· ***Identification number:***	*UN2320*
· ***Packing group:***	*III*
· ***Proper shipping name (technical name):***	*TETRAETHYLENEPENTAMINE*
· ***Label***	*8*

· ***Land transport ADR/RID (cross-border):***

· ***ADR/RID class:***	*8 Corrosive substances*
· ***Danger code (Kemler):***	*80*
· ***UN-Number:***	*2320*
· ***Packaging group:***	*III*
· ***Label:***	*8*
· ***Description of goods:***	*2320 TETRAETHYLENEPENTAMINE*

· ***Maritime transport IMDG:***

· ***IMDG Class:***	*8*
· ***UN Number:***	*2320*
· ***Label***	*8*
· ***Packaging group:***	*III*
· ***EMS Number:***	*F-A,S-B*
· ***Marine pollutant:***	*No*

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Material Safety Data Sheet
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Trade name: CAT.190

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· **Propper shipping name:** TETRAETHYLENEPENTAMINE

· **Air transport ICAO-TI and IATA-DGR:**

· **ICAO/IATA Class:**	8
· **UN/ID Number:**	2320
· **Label**	8
· **Packaging group:**	III
· **Propper shipping name:**	TETRAETHYLENEPENTAMINE

15 Regulations

· **Sara**

· **Section 355 (extremely hazardous substances):**
Substance is not listed.

· **Section 313 (Specific toxic chemical listings):**
Substance is not listed.

· **TSCA (Toxic Substances Control Act):**
Substance is listed.

· **Proposition 65**

· **Chemicals known to cause cancer:**
Substance is not listed.

· **Chemicals known to cause reproductive toxicity for females:**
Substance is not listed.

· **Chemicals known to cause reproductive toxicity for males:**
Substance is not listed.

· **Chemicals known to cause developmental toxicity:**
Substance is not listed.

· **Cancerogenity categories**

· **EPA (Environmental Protection Agency)**
Substance is not listed.

· **IARC (International Agency for Research on Cancer)**
Substance is not listed.

· **NTP (National Toxicology Program)**
Substance is not listed.

· **TLV (Threshold Limit Value established by ACGIH)**
Substance is not listed.

· **NIOSH-Ca (National Institute for Occupational Safety and Health)**
Substance is not listed.

· **OSHA-Ca (Occupational Safety & Health Administration)**
Substance is not listed.

(Contd. on page 8)

USA

Material Safety Data Sheet
acc. to ISO/DIS 11014

Printing date 04/19/2007 *Reviewed on 05/10/2006*

Trade name: CAT.190

(Contd. of page 7)

· ***Product related hazard informations:***
The product has been classified and marked in accordance with directives on hazardous materials.

· ***Hazard symbols:***
Corrosive
Dangerous for the environment

· ***Risk phrases:***
Harmful in contact with skin and if swallowed.
Causes burns.
Toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
Irritating to respiratory system and skin.
May cause sensitisation by inhalation and skin contact.
Risk of serious damage to eyes.

· ***Safety phrases:***
Keep locked up and out of the reach of children.
In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
Wear suitable protective clothing, gloves and eye/face protection.
In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
Do not empty into drains, dispose of this material and its container at hazardous or special waste collection point.
Use only in well-ventilated areas.
Do not mix with acids.
After contact with skin, wash immediately with plenty of soap and water.

· ***Special labeling of certain preparations:***
Only for trade users / technical specialists
Keep out of the reach of children.

16 Other information

This information is based on our present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship. The information given and the recommendations made herein apply to our product alone and are not combined with other product(s). Such are based on our research and on data from other reliable sources and are believed to be accurate. No guarantee of accuracy is made. It is the user's responsibility before using any product to verify this data under their own operating conditions and to determine whether the product is suitable for their purposes.

· ***Department issuing MSDS:*** *Product safety department.*
· ***Contact:*** *Paul C. Harrington*

USA

Appendix D5: MSDS for WD40

The following pages were taken from WD-40 Company © Catalog (www.wd40.com)

WD-40 Company

Material Safety Data Sheet

1 - Chemical Product and Company Identification

Manufacturer: WD-40 Company	**Chemical Name: Organic Mixture**
Address: 1061 Cudahy Place (92110) P.O. Box 80607 San Diego, California, USA 92138 –0607	**Trade Name: WD-40 Aerosol**
Telephone: 1-800-448-9340 Emergency only: 1-888-324-7596 (PROZAR) Information: 1-888-324-7596	**Product Use: Cleaner, Lubricant, Penetrant** **MSDS Date Of Preparation: 5/16/07**

2 – Hazards Identification

Emergency Overview:
DANGER! Harmful or fatal if swallowed. Flammable aerosol. Contents under pressure. Avoid eye contact. Use with adequate ventilation. Keep away from heat, sparks and all other sources of ignition.

Symptoms of Overexposure:
Inhalation: High concentrations may cause nasal and respiratory irritation and central nervous system effects such as headache, dizziness and nausea. Intentional abuse may be harmful or fatal.
Skin Contact: Prolonged and/or repeated contact may produce mild irritation and defatting with possible dermatitis.
Eye Contact: Contact may be mildly irritating to eyes. May cause redness and tearing.
Ingestion: This product has low oral toxicity. Swallowing may cause gastrointestinal irritation, nausea, vomiting and diarrhea. The liquid contents are an aspiration hazard. If swallowed, can enter the lungs and may cause chemical pneumonitis.
Chronic Effects: None expected.
Medical Conditions Aggravated by Exposure: Preexisting eye, skin and respiratory conditions may be aggravated by exposure.

Suspected Cancer Agent:
Yes No X

3 - Composition/Information on Ingredients

Ingredient	CAS #	Weight Percent
Aliphatic Hydrocarbon	64742-47-8 64742-48-9 64742-88-7	45-50
Petroleum Base Oil	64742-65-0	15-25
LVP Aliphatic Hydrocarbon	64742-47-8	12-18
Carbon Dioxide	124-38-9	2-3
Non-Hazardous Ingredients	Mixture	<10

4 – First Aid Measures

Ingestion (Swallowed): Aspiration Hazard. DO NOT induce vomiting. Call physician, poison control center or the WD-40 Safety Hotline at 1-888-324-7596 immediately.
Eye Contact: Flush thoroughly with water. Get medical attention if irritation persists.
Skin Contact: Wash with soap and water. If irritation develops and persists, get medical attention.

Inhalation (Breathing): If irritation is experienced, move to fresh air. Get medical attention if irritation or other symptoms develop and persist.

5 – Fire Fighting Measures

Extinguishing Media: Use water fog, dry chemical, carbon dioxide or foam. Do not use water jet or flooding amounts of water. Burning product will float on the surface and spread fire.
Special Fire Fighting Procedures: Firefighters should always wear positive pressure self-contained breathing apparatus and full protective clothing. Cool fire-exposed containers with water. Use shielding to protect against bursting containers.
Unusual Fire and Explosion Hazards: Contents under pressure. Aerosol containers may burst under fire conditions. Vapors are heavier than air and may travel along surfaces to remote ignition sources and flash back.

6 – Accidental Release Measures

Wear appropriate protective clothing (see Section 8). Eliminate all sources of ignition and ventilate area. Leaking cans should be placed in a plastic bag or open pail until the pressure has dissipated. Contain and collect liquid with an inert absorbent and place in a container for disposal. Clean spill area thoroughly. Report spills to authorities as required.

7 – Handling and Storage

Handling: Avoid contact with eyes. Avoid prolonged contact with skin. Avoid breathing vapors or aerosols. Use with adequate ventilation. Keep away from heat, sparks, hot surfaces and open flames. Wash thoroughly with soap and water after handling. Do not puncture or incinerate containers. Keep can away from electrical current or battery terminals. Electrical arcing can cause burn-through (puncture) which may result in flash fire, causing serious injury. Keep out of the reach of children.
Storage: Do not store above 120°F or in direct sunlight. U.F.C (NFPA 30B) Level 3 Aerosol.

8 – Exposure Controls/Personal Protection

Chemical	Occupational Exposure Limits
Aliphatic Hydrocarbon	100 ppm TWA (ACGIH) 1200 mg/m3 TWA (manufacturer recommended)
Petroleum Base Oil	5 mg/m3 TWA (OSHA/ACGIH)
LVP Aliphatic Hydrocarbon	1200 mg/m3 TWA (manufacturer recommended)
Carbon Dioxide	5000 ppm TWA (OSHA/ACGIH), 30,000 ppm STEL (ACGIH)
Non-Hazardous Ingredients	None Established

The Following Controls are Recommended for Normal Consumer Use of this Product
Engineering Controls: Use in a well-ventilated area.
Personal Protection:
Eye Protection: Avoid eye contact. Safety glasses or goggles recommended.
Skin Protection: Avoid prolonged skin contact. Chemical resistant gloves recommended for operations where skin contact is likely.
Respiratory Protection: None needed for normal use with adequate ventilation.

For Bulk Processing or Workplace Use the Following Controls are Recommended
Engineering Controls: Use adequate general and local exhaust ventilation to maintain exposure levels below that occupational exposure limits.
Personal Protection:
Eye Protection: Safety goggles recommended where eye contact is possible.
Skin Protection: Wear chemical resistant gloves.
Respiratory Protection: None required if ventilation is adequate. If the occupational exposure limits are exceeded, wear a NIOSH approved respirator. Respirator selection and use should be

based on contaminant type, form and concentration. Follow OSHA 1910.134, ANSI Z88.2 and good Industrial Hygiene practice.
Work/Hygiene Practices: Wash with soap and water after handling.

9 – Physical and Chemical Properties

Boiling Point:	323°F (minimum)	Specific Gravity:	0.817 @ 72°F
Solubility in Water:	Insoluble	pH:	Not Applicable
Vapor Pressure:	110 PSI @ 70°F	Vapor Density:	Greater than 1
Percent Volatile:	74%	VOC:	412 grams/liter (49.5%)
Coefficient of Water/Oil Distribution:	Not Determined	Appearance/Odor	Light amber liquid/mild odor
Flash Point:	131°F (concentrate) Tag Closed Cup	Flammable Limits: (Solvent Portion)	LEL: 1.1% UE:: 8.9%

10 – Stability and Reactivity

Stability: Stable
Hazardous Polymerization: Will not occur.
Conditions to Avoid: Avoid heat, sparks, flames and other sources of ignition. Do not puncture or incinerate containers.
Incompatibilities: Strong oxidizing agents.
Hazardous Decomposition Products: Carbon monoxide and carbon dioxide.

11 – Toxicological Information

The oral toxicity of this product is estimated to be greater than 5,000 mg/kg based on an assessment of the ingredients. This product is not classified as toxic by established criteria. It is an aspiration hazard.
None of the components of this product is listed as a carcinogen or suspected carcinogen or is considered a reproductive hazard.

12 – Ecological Information

No data is currently available.

13 - Disposal Considerations

If this product becomes a waste, it would be expected to meet the criteria of a RCRA ignitable hazardous waste (D001). However, it is the responsibility of the generator to determine at the time of disposal the proper classification and method of disposal. Dispose in accordance with federal, state, and local regulations.

14 – Transportation Information_

DOT Surface Shipping Description: Consumer Commodity, ORM-D
IMDG Shipping Description: Aerosols, 2, UN1950

15 – Regulatory Information

U.S. Federal Regulations:
CERCLA 103 Reportable Quantity: This product is not subject to CERCLA reporting requirements, however, oil spills are reportable to the National Response Center under the Clean Water Act and many states have more stringent release reporting requirements. Report spills required under federal, state and local regulations.
SARA TITLE III:
Hazard Category For Section 311/312: Acute Health, Fire Hazard, Sudden Release of Pressure

Section 313 Toxic Chemicals: This product contains the following chemicals subject to SARA Title III Section 313 Reporting requirements: None
Section 302 Extremely Hazardous Substances (TPQ): None
EPA Toxic Substances Control Act (TSCA) Status: All of the components of this product are listed on the TSCA inventory
Canadian Environmental Protection Act: All of the ingredients are listed on the Canadian Domestic Substances List or exempt from notification
Canadian WHMIS Classification: Class B-5 (Flammable Aerosol)
This MSDS has been prepared according to the criteria of the Controlled Products Regulation (CPR) and the MSDS contains all of the information required by the CPR.

16 – Other Information:

HMIS Hazard Rating:
Health – 1 (slight hazard), Fire Hazard – 4 (severe hazard), Reactivity – 0 (minimal hazard)

SIGNATURE: Peter P. Ly TITLE: Director of Global Quality Assurance

REVISION DATE: Revision Date: May 2007 SUPERSEDES: December 2004

Appendix E

Thermal Epoxy

Appendix E1: Mechanical Properties and Preparation Instructions for Thermal Epoxy P/N 50-3100

The following pages were taken from the Epoxies, Etc... © Catalog (www.epoxies.com)

Epoxies, Etc...

Epoxy, Urethane & Silicone Formulations

50-3100

HIGH THERMAL K HEAT TRANSFER EPOXY RESIN

DESCRIPTION:

50-3100 is designed for the fastest and most continuous high heat transfer. 50-3100 measures several times faster heat dissipation than other commercially available types. The most important breakthrough is the handling of 50-3100. This system can be easily mixed and poured to form a dimensionally stable heat transfer package.

Mil Spec Thermal Shock Requirements are exceeded by 50-3100 while maintaining low thermal expansion.

Outstanding features are the excellent thermal shock and high temperature resistance (class H with catalyst 105) properties.

50-3100 is ideal for large castings because of its low shrinkage and low exotherm during cure.

Typical applications include encapsulation of power supplies, transformers, coils, insulators, protective covering for chips, temperature probes, etc…

CHOICE OF CURING AGENTS:

CATALYST 190: Room temperature curing with a 45 minute pot life. Tough and rigid at all temperatures up to 150°C.

CATALYST 150: Room temperature curing with a 30 minute pot life. Low viscosity and easy handling properties. Excellent adhesion. Has a service temperature up to 150°C (300°F). Will soften slightly above 121°C (250°F).

CATALYST 105: Heat curing with a pot life of 4 hours. Low viscosity with excellent handling properties. Excellent thermal and mechanical shock. Best catalyst for electrical and physical properties at temperatures above 121°C (250°F). Can be used up to 205°C (400°F).

TYPICAL SPECIFICATIONS:

Viscosity @ 25°C, cps, Resin	180,000	
Viscosity @ 25°C (Cat.190) cps	32,000	
Viscosity @ 25°C (Cat.150) cps	6,000	
Viscosity @ 65°C (Cat.105) cps	45,000	**over

1-800-EPOXIES (376-9437) • 401-946-5564 • Fax: 401-946-5526
21 Starline Way • Cranston, RI 02921 USA
www.epoxies.com • service@epoxies.com

Specific Gravity, 25°C/25°C, Resin	2.0
Hardness, Shore D	90
Linear Shrinkage, in./in.	.003
Tensile Strength, psi	8,800
Compressive Strength, psi	15,000
Operating Temp. Range,°C	-60 to +205
Coefficient of Expansion, °C	30×10^{-6}
Dielectric Strength, Volts/Mil	485
Dielectric Constant at 60 HZ	6.4
Volume Resistivity, OHM-CM	1.5×10^{15}
Dissipation Factor, 60 HZ	.015
Heat Distortion, °C	120
Thermal Conductivity, BTU/hr/ft^2/°F/in.	15

INSTRUCTIONS FOR USE:

A. WITH CATALYST 190
1. By weight, thoroughly mix 5 parts Catalyst 190 to 100 parts 50-3100 resin.
2. By volume, thoroughly mix 10 parts Catalyst 190 to 100 parts 50-3100 resin.
3. Degas and pour, cure at room temperature for 24 hours @ 25°C ambient or for 2 hours at 66°C (155°F).

B. WITH CATALYST 105
1. By weight, thoroughly mix 6 parts Catalyst 105 to 100 parts 50-3100 resin.
2. By volume, thoroughly mix 9 parts Catalyst 105 to 100 parts 50-3100 resin.
3. Degas and pour, cure with one of the following schedules:

   a. 74°C (165°F) 16 hours
   b. 100°C (212°F) 2 hours
   c. 125°C (275°F) 1 hour

C. WITH CATALYST 150
1. By weight, thoroughly mix 12 parts Catalyst 150 to 100 parts 50-3100 resin.
2. By volume, mix 24 parts Catalyst 150 to 100 parts 50-3100 resin.
3. Degas and pour, cure for 24 hours at room temperature or for 2 hours at 66°C (155°F).

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